A MODEL APPROACH FOR PREDICTING COMMERCIAL CONSTRUCTION SITE ACCIDENTS

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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Safety should be one of the most important concerns in the construction industry because accidents at construction sites cause deaths, personal injuries and economic losses, estimated by Levitt and Samelson to be $19.5-billion each year, nationally.

In Florida, the Department of Labor and Employment Security reported that in 1985, 17,461 disabling injuries cost the construction industry over $127-million. These statistics, coupled with the spiralling rates of workers' compensation insurance and stricter Occupational Safety and Health Administration (OSHA) regulations being proposed by national lawmakers, are indications that there is a need for enhancements that can increase the effectiveness of existing safety programs. The ability to predict accidents within the industry

can help make existing safety programs more effective and construction sites safer. Historically, prediction of accidents in the construction industry, in general, has been difficult because of the lack of relevant data and a scientifically valid method. The objective of this research is to develop a methodology that will enable the construction industry to predict accidents.

This dissertation presents a model approach for predicting construction site accidents. The identification of the most significant factors contributing to construction accidents will facilitate the accident prediction process. Therefore the critical subject of factor identification is discussed and a data collection scheme is developed.

A comprehensive approach, simplified to facilitate practical application within the construction industry, is presented and illustrated with an accident prediction model developed from a case study using a data base of 1078 accident observations collected from 85 different projects in four Florida counties. This study should be of interest to construction engineers and contractors, owners and managers of construction projects, OSHA, Department of Labor, Bureau of Labor Statistics, safety professionals and advocates, insurance companies and all who are concerned about the vital subject of improving safety on construction sites.

CHAPTER 1

INTRODUCTION

Statement of the Problem

As one of the largest industries in the United States the construction industry has been plagued continuously over the years with one of the highest rates of accidents among all other industries. Table 1 illustrates that the incidence rate of recordable injuries in the construction industry is twice that of the industrial average.

Even though the construction industry employs only an estimated 6% of the industrial work force in the United States, it accounts for an estimated 20% of all occupational fatalities each year, according to statistics compiled by the National Safety Council and illustrated in Table 2.

The National Safety Council (1986, 1987a and 1988a), a nongovernmental and not for profit organization chartered by an act of congress, estimates that there are approximately 220,000 disabling injuries and 2,200 deaths in the United States each year as a result of accidents in the construction industry.

Table 1. National Industrial Accident Disabling Injury and Death Statistics (1960-1983): Construction Industry vs. All Other Industries Combined.

	DISABLING INJURIES PER 100,000 WORKERS			ACCIDENTAL DEATHS PER 100,000 WORKERS		
YEAR	(1) ALL INDUST.	(2) CONST.	(2/1) RATIO	(3) ALL INDUST.	(4) CONST.	(4/3) RATIO
1960	3,110	6,100	1.9	22	73	3.3
1961	2,960	5,920	2.0	21	68	3.2
1963	2,940	6,215	2.1	21	74	3.5
1965	3,010	6,080	2.0	20	73	3.6
1967	2,945	6,050	2.1	19	71	3.7
1968	2,785	6,000	2.2	18	70	3.9
1969	2,785	6,000	2.2	18	70	3.9
1970	2,775	6,154	2.2	18	72	4.0
1971	2,875	6,316	2.2	18	71	3.9
1972	2,916	6,500	2.2	17	70	4.1
1976	2,506	5,405	2.2	14	57	4.1
1977	2,530	5,715	2.3	14	60	4.3
1978	2,321	5,218	2.3	14	57	4.1
1980	2,273	4,286	1.9	14	45	3.2
1981	2,105	3,819	1.8	13	40	3.1
1982	2,104	3,818	1.8	12	40	3.3
1983	2,100	3,804	1.8	12	40	3.3
Average Ratio			2			3.7

Source: National Safety Council (1986)

Table 2. National Annual Industrial Employment and Accident Fatalities Statistics (1985-1987): Construction Industry vs. All Other Industries.

YEAR	INDUSTRY	# OF WORKERS	% OF TOTAL	# OF DEATHS	% OF TOTAL
1985	All Industries	106,400,000	100	11,600	100
	Construction	6,000,000	5.6	2,200	18.9
1986	All Industries	108,900,000	100	10,700	100
	Construction	6,300,000	5.8	2,100	19.6
1987	All Industries	111,700,000	100	11,100	100
	Construction	6,300,000	5.6	2,200	19.8

Source: National Safety Council (1986, 1987a and 1988a)

As can be seen in Table 3, fatalities in the construction industry have averaged about 2,300 annually over a ten-year period. Accidents at construction sites, like all other accidents, create humanitarian concerns because the resulting personal injuries and deaths usually inflict pain and suffering on the victims and their families. However, in addition to the humanitarian concerns for the individuals involved, these accidents also have an economic impact. The reason being that construction site accidents also cost the construction industry and tax payers billions of dollars each year. A study conducted by Stanford University and released by the Business Round Table (1982) as part of its construction industry cost effectiveness report, estimates that the direct and indirect costs of accidents in the construction industry nationally were approximately $8.9-billion (1979 dollars) annually. This translated to about $24-million per day. In more recent times, Levitt and Samelson (1987), indicate that a conservative estimate of the financial cost of accidents to the construction industry, developed from 1979-1980 figures, is approximately $19.5-billion per year.

One of the results of the high number of accidents at construction sites is the spiraling cost of workers' compensation insurance. Grogan (1989) reported that the average overall rate increase requested by the insurance companies nationwide was 14.8% in 1989. He also reported that some

Table 3. 10-year National Annual Construction Industry Accident Fatalities Statistics (1978-1987).

YEAR	# OF DEATHS
1978	2,600
1979	2,600
1980	2,500
1981	2,300
1982	2,100
1983	2,100
1984	2,200
1985	2,400
1986	2,400
1987	2,200
Average number of deaths per year =	2,340

Source: National Safety Council (1988a)

contractors in Florida had rate increases as high as 28.8% in 1989. However, since that time, Kirby (1990) has estimated that workers' compensation insurance has catapulted an average of 66% in the past two years in Florida. For example, according to Kirkland (1990), figures compiled from the Florida Department of Insurance indicate that a roofer in 1985 paid $24.62 in workers' compensation insurance premiums annually for every $100 of payroll. That roofer in 1990 now pays $55 annually per $100 of payroll.

Table 4, which shows a comparison of workers' compensation rates in Florida and six other southeastern states for several construction trades, also indicates that workers' compensation premiums are much higher in Florida than most of the southeastern states.

Even though efforts (such as the development of accident prevention manuals and the proposal of new tougher regulations) have been made in the past as well as in recent times, accidents in the construction industry continue to be a major problem. For example, in the State of Florida as depicted in Table 5, there were 11,871 disabling injuries on construction sites at a cost of $90,134,000 in 1982. By 1985 the number of injuries had increased to 17,461 at a cost of $127,214,000, triggering the astronomical increases in the rates for workers' compensation insurance for most contractors in Florida.

Table 4. 1990 Workers' Compensation Rates (Annual Cost per $100 of Payroll): Florida vs. Six Southeastern States.

TRADE	FLA. $	ALA. $	GA. $	LA. $	MISS. $	N.C. $	S.C. $
Carpentry	28.18	14.98	19.18	11.92	8.96	6.64	14.54
Drywall	23.27	7.88	10.92	7.49	7.05	4.43	9.65
Electrical	12.89	5.86	6.92	5.59	4.93	4.32	8.20
Insulation	25.66	11.17	15.42	8.20	6.92	6.14	11.46
Ironwork	48.03	23.21	22.52	24.13	22.27	19.37	11.28
Landscaping	13.73	5.79	11.73	8.03	6.56	3.22	5.18
Painting	30.18	11.54	13.00	13.24	6.64	5.05	9.36
Plastering	31.60	9.38	13.86	8.86	9.94	8.46	9.58
Plumbing	16.01	6.53	7.41	6.29	3.36	4.46	3.44
Roofing	55.77	25.13	30.40	20.21	15.30	12.70	17.21
Sheet metal	19.12	13.57	11.72	7.76	7.80	5.31	8.84

Source: The Gainesville Sun, March 28, 1990.

Table 5. Florida Construction Industry Annual Accident Statistics (1982-1985): Changes in the Number of Disabling Injuries and Related Costs.

YEAR	NO. OF DISABLING INJURIES	TOTAL COST
1982	11,871	$ 90,134,025
1983	12,540	86,330,677
1984	13,179	98,412,454
1985	17,461	127,213,451
% CHANGE (1982-1985)	+ 47%	+ 41%

Source: Florida Department of Labor and Employment Security, Division of Workers' Compensation (1982-1985).

The illustrative alarming statistics presented here are clear indications that there is a need for research and innovative concepts that can help reduce the number of accidents on construction sites. Many studies have been done on the general topic of safety and lost time accidents, and there are studies currently underway to quantify and establish the relationship between the direct and indirect costs of accidents in order to permit a more effective measurement of the total cost of construction site accidents. In addition to the above studies, several safety plans and accident prevention manuals (such as the ones by the Associated General Contractors, Associated Builders and Contractors and the U.S. Army Corps of Engineers) have been developed. New legislation (proposed after 28 construction workers were killed at the site of the L'ambiance Plaza project in Bridgeport, Connecticut, in 1987) titled "The Construction Safety and Health Improvement Act" would, if passed:

a). Require the involvement of a State Registered Professional Engineer (PE) to oversee safety on virtually all residential and commercial projects;

b). Require contractors to obtain a permit issued by a PE before beginning many construction site tasks such as the erection of scaffolding that are more than three stories high, demolition of buildings that are more than three stories high, as well as "any other operation in

which an exposure to death or serious bodily harm is involved";

c). Authorize PEs to investigate any construction site incidents that cause serious injury or threaten life, and require the engineers to file the results of their investigations with the Occupational Safety and Health Administration; and

d). Require nearly all developers to file a "construction process plan and hazard analysis" with a PE before beginning each construction project.

Previous and new efforts such as safety plans, manuals and legislation have played significant roles in safety improvement. However, one of the major shortcomings of such efforts is that they are mostly general plans, manuals and legislation often developed without consideration for the unique characteristics of each type of project and the major phases within each project.

While existing efforts are positive steps in the right direction, it is the premise of this thesis that accident prevention efforts will be more effective, if accidents can be predicted prior to the start of each project. This will enable the parties involved (owners, contractors, subcontractors, developers, safety engineers, etc.) to develop safety plans that are tailored specifically for each type of project. There is therefore a need to develop a methodology that can aid the construction industry to predict accidents on

construction project sites. The ability to predict the number of accidents for each project will enable contractors to evaluate the effectiveness of their safety programs and can help reduce the number of accidents. In other words

ACCIDENT PREVENTION = PREDICTION + PRE-PLANNING + EDUCATION.

Objective of the Study

The overall objective of this study is to develop a methodology that can aid the construction industry to scientifically predict accidents on commercial construction sites. Once developed, the model approach will be demonstrated by collecting accident data from past construction projects in four Florida counties, analyzing the data to determine the most significant factors that contribute to construction site accidents and then using these factors to develop an illustrative model. The more elaborate details of many existing safety programs, legislation and sophisticated mathematical theories will be intentionally omitted so that greater attention can be paid to the identification of the appropriate factors, collection and analysis of accident data, and the development of a systematic approach that can be easily comprehended and utilized by safety and field personnel, within the construction industry, for whom it is intended.

Significance of the Study

Levitt and Samelson (1987) in pointing out the high costs of accidents to the construction industry stated that:

> Accidents are controllable and the discussion of these costs alone indicates that substantial savings can be made by reducing accidents. (p. 23)

The best way to reduce the number of accidents is to prevent accidents from happening. Models from the results of this study can play a significant role in reducing the number of accidents. Ultimately, a reduction in the number of accidents at construction sites can lead to a reduction in workers' compensation insurance premiums. The availability of a systematic methodology to analyze and predict accidents can make it possible for the appropriate precautions to be taken prior to beginning each project. The concept can also be used to predict accidents so that safety programs can be tailored to individual projects and contractors. As the National Safety Council pointed out (1982):

> The best way to prevent losses due to accidents and occupational illness is to develop a solid, working program for accident prevention. Job safety analysis has proven time and again to be an accident and occupational illness prevention tool in many industries over the past years. (p. 2)

Many safety programs have already been developed for the construction industry. This concept can be used as a tool to make such programs more effective and thereby prevent accidents.

Finally, the results of this study can greatly expand available knowledge on safety in the construction industry and can lead to the development of other models for improving

safety on other categories of construction, such as heavy, residential and industrial construction projects.

Limitations and Assumptions

Limitations

1. The source of data used in this study is limited geographically to contractors selected from four Florida counties, namely, Alachua, Duval, Hillsborough and Pinellas.
2. Construction accident statistical and other data were obtained from a limited sample of 85 projects and were reported by general contractors through surveys and personal interviews.
3. Because this research is not a designed experiment,the database created consisted of naturally occurring accidents of all types without any weighting factors for severity or seriousness.
4. All illustrative data and examples are limited to commercial construction projects only. Other categories of construction are excluded from this study.
5. The approach developed in this study is intended to aid in the development of models for the prediction of only the estimated number of accidents to be expected. It is therefore not intended to be used in developing models that can predict logistical details of accidents such as the severity of the accidents to be expected or specific details

(age, occupation, sex, race etc.) of workers who may be potentially injured.

Finally it should also be noted that other families of factors such as project design, number of workers, weather and type of structure are not given any attention in this study due to lack of relevant data.

Assumptions

The following assumptions of this study should be recognized:

1. The contractors surveyed responded in an honest manner and provided accurate accident and project information.
2. Statistical and other data obtained from the Department of Labor and Employment Security, Division of Workers' Compensation, and the National Safety Council are accurate.
3. The errors or residuals in the regression models are normally distributed.
4. The average distribution is zero and the variance is the same for all values of independent variables.
5. All errors are independent and the value of the random error term ϵ, which accounts for all unexplained and unpredictable factors that may influence the value of the dependent value, is equal to zero.
6. Every project used in the study is independent from every other project, even in cases where data for different projects were obtained from the same contractor.

Definition of terms

Several terms or abbreviations that may be new to some readers or may be peculiar to this study appear throughout this dissertation. The most important of these terms are defined in the following section as clarification of the context in which they are used in the research:

Accident is an unplanned act, event or occurrence, within a sequence of events, which can cause unintended personal injury or death, property damage or both.

ASCII is the acronym for American Standard Code for Information Interchange.

Categories of construction are commercial, residential, industrial, heavy and institutional.

Commercial construction refers to projects such as office buildings, shopping centers, shopping malls, hotels, airport terminals, clubhouses, nursing homes, parking garages, libraries, correctional facilities, schools, theatres, banks and churches.

General contractors describes those professionals engaged in the construction of commercial buildings.

Dependent (or response) variable is the number of accidents to be expected on a construction site.

Disabling injury is an injury that can cause death, permanent disability, or any degree of temporary total disability beyond the day of the accident.

Experimental unit is each contractor in the universe

Extraneous factor is a factor that is not of primary interest to a researcher but may have an effect on the dependent variable. For this study, the severity or levels of seriousness of accidents to be expected and the age, occupation, sex, race, etc. of workers who may be potentially injured will be considered as extraneous factors.

Fatality is an accident which results in one or more deaths within a year after the occurrence of an accident.

Independent variable also known as factor or parameter is a set of treatments that is to be evaluated by the research work (size of contractor, experience of contractor, size of project, contract duration, type of structure, etc.).

Hazard is a condition, act or event that has the potential of causing an accident or illness.

Incidence rate, according to OSHA, is the number of injuries, deaths and/or illnesses or lost workdays per 100 full-time employees.

Level of a factor is each possible setting of a factor, for example, an accident may have several levels from a minor cut on a finger to a severe groin bruise or a fatality.

Model is a verbal or graphical description or analogy that can be used to help visualize an item, procedure or technique that is not otherwise easily observed.

OSHA is Occupational Safety and Health Administration.

Phase is used to describe a physical portion or milestone of a construction project, such as sitework, substructure, superstructure, roofing, exterior cladding, interior work, etc.

Population is the collection of the number of accidents for all contractors in the universe.

P-sample is the collection of the number of accidents from the general contractors included in the study.

Statistic is an estimate or a numerical fact from a set of observations, for example, the average annual volume of a contractor.

Universe is all general contractors in North Florida with at least one project where an accident has occurred between 1984 and 1989.

U-sample is the collection of general contractors included in the study.

Variable is a characteristic that varies from one member to another. A variable can be either continuous or discrete. For example, the annual volume of a contractor as he grows from year to year is continuous, because as he grows from say \$5-million to \$10-million his volume passes through all the values between the two limits. On the other hand, the number of rooms in a house is discrete, because it can only take certain values such as 1, 2, 3, 4 and so on.

CHAPTER 2

REVIEW OF LITERATURE

Introduction

One theme of this study is to utilize past experiences and research as much as possible. As such an extensive literature search was carried out. A summary of the literature review is organized into seven major sections. In the first section a brief history and background of safety in general is presented. The second section focusses on the general categories of construction projects. The third section examines the major phases within a commercial construction project. The fourth section focusses on the causes of accidents on construction sites. The fifth section examines existing and proposed safety regulations pertaining to the construction industry. The sixth section reviews previous work on safety analyses and examples of methods of analyses that pertain to the determination of potential hazards. The seventh section is on previous works related to accident prediction models in general.

History and Background

Dr. William Properzio, the director of the Department of Environmental Engineering at the University of Florida and an expert in safety matters, summarized the question of safety in general when he stated in his graduate industrial safety class in 1989 that:

> safety is an issue about which few are well-informed, many are concerned and everyone has a stake in the outcome.

This is very true in the construction industry because the injured worker suffers through physical damage to the body, pain and often trauma from the accident; the contractor loses productivity as well as profit due to increase in his workers' compensation insurance rates and the uninsured costs resulting from the accident; the owner pays for the cost of accidents in the form of higher overhead costs or higher bids submitted by the contractor on future work and possible third-party liability lawsuits; tenants of the facility absorb a portion of the cost by paying higher lease rates, rents or sale prices for space; and the general public pays for part of the cost of accidents in the form of higher sale prices on goods and services obtained from the tenants of the constructed facility. This view was also shared by Levitt and Samelson (1987) when they stated that:

> Accidents cost the U.S. construction industry billions of dollars annually. In the short term, these costs are absorbed by contractors in the form of higher insurance premiums and indirect costs. But they are ultimately

> passed on to construction buyers in the form of higher reimbursable costs or higher bids on future work. (p. 173)

A business roundtable study (1982) determined that even on hard money projects, accidents result in higher costs for construction buyers through delays and potential third-party liability lawsuits.

In spite of the higher costs of accidents, historically, there has been a myth in almost all industries that safety can only be achieved at the expense of even higher costs and slower work schedules. As written by Hammer (1985),

> When the Railway Safety Act was being considered in 1893, a railroad executive said that it would cost less to bury a man killed in an accident than to put air brakes on a car. This railroad executive probably was not an evil or malicious man. In all probability he believed in God, was a good husband and loving father, and patted his dog when he came home. He would have done anything to avoid injury to his family or dog, but safety of other people was considered only in monetary terms. (p. 1)

However, according to Levitt and Samelson (1987), when properly documented and accounted for, the cost of accidents in the construction industry far exceeds the cost of implementing a safety program and that:

> The safest managers in many of the construction firms that we studied over the past 15 years turned out also to be the ones in their organizations with the best cost and schedule performance. (p. xvi)

The history of industrial safety can be traced to the late 1800s when the Railway Safety Act was proposed. However, the American Safety Movement did not begin until 1906 when the

high number of deaths in the steel industry led to the creation of the United States Steel Corporation Committee to inspect work sites and promote accident prevention. According to Simmonds and Grimaldi (1963), the work of this committee was effective in reducing the number of occupational injuries within the corporation and resulted in the saving of several lives as well as millions of dollars in insurance fees and medical expenses.

In spite of the success of the United States Steel Corporation safety plan, the total number of occupational deaths was still very high. For example in 1912, occupational deaths were estimated between 18,000 and 21,000 each year. In 1987, with a work force whose size was more than double that in 1912, the total number of deaths for all industries was estimated by the National Safety Council to be 11,100. These alarming statistics and public pressure led to the formation of the National Safety Council, a nationwide voluntary safety movement organized to help prevent accidents in all industries. In 1915, the American Society of Safety Engineers (ASSE) was incorporated within the National Safety Council to enforce safe engineering practices. ASSE has since become an independent organization dedicated to reducing occupational accidents through sound engineering and the development of safety engineering as a profession.

Even though the establishment of safety organizations encouraged a strong move towards a safer working environment, deaths at industrial workplaces averaged close to 17,000 annually in the 1940s, according to the National Safety Council (1986). This eventually led to the establishment of the President's Industrial Safety Council by President Harry S. Truman. This council was made up of representatives from government, labor, management and insurance companies. Its objective was to hold a series of annual meetings to discuss jobsite safety, develop methods for reducing occupational injuries and make recommendations for the correction of unsafe practices.

In 1969, the Coal Mine Health and Safety Act was passed to protect the health and lives of miners. By 1970, the number of industrial accidents had been reduced from what they were in the 1940s. However, the statistics on annual deaths were still disturbing. U.S. Department of Labor, Division of Occupational Safety and Health Administration reported that

1. Job-related accidents accounted for more than 14,000 deaths annually;
2. Ten times as many workdays were lost from job-related accidents as from strikes; and
3. Nearly 2.5 million workers were disabled from occupational injuries.

Faced with these statistics and a realization that the level of risk at workplaces was unacceptable for workers, the

United States Congress in December 1970 passed the Williams-Steiger Occupational Safety and Health Act (OSHAct) of 1970. The act became effective on April 28, 1971 and as stated by Hammer (1985):

> The Occupational Safety and Health Act has the fundamental aim of ensuring so far as possible every working man and woman in the nation safe and healthful working conditions and to preserve our human resources. (p. 51)

For the first time in the history of safety, a set of standards was developed to regulate the workplace and determine acceptable and nonacceptable practices. Many new organizations were set up as a result of the act including

a). The Occupational Safety and Health Administration (OSHA), which was created within the Department of Labor and given the authority to establish and enforce safety and health standards required to provide workers with safe and healthy working environment; and to encourage both employers and employees to reduce workplace hazards and to implement new and improved safety and health programs.

b). The Occupational Safety and Health Review Commission (OSHRC), a quasi-judicial board composed of three members appointed by the President and whose function is to hear and review alleged violations and to issue corrective orders and assess penalties, where warranted.

c). The National Institute for Occupational Safety and Health (NIOSH) responsible for the conduct of research.

General Categories of Construction Projects

The nature of the construction industry and the variations within it often make it difficult to categorize construction projects. As suggested by Hardie (1987):

> The construction industry embraces many types of construction work, all of which can be classified under two broad headings: heavy construction, which includes bridges, dams, roads, tunnels, mills and the like; and building construction, which includes residential and non-residential construction. (p. 4)

However, Barrie and Paulson (1978) pointed out:

> It is difficult, if not impossible, to neatly categorize so great a spectrum of projects. The exceptions, the ones that transcend the boundaries, often seem to outnumber those that are clearly recognizable. What follows, nevertheless, are four somewhat arbitrary but generally accepted major types of construction. In large measure, these categories parallel the general specialties into which designers and constructors group themselves. (p. 8)

Based on the above reasoning, Barrie and Paulson categorized construction projects into four groups

1. Residential construction
2. Building construction
3. Heavy engineering construction
4. Industrial construction.

Bentil (1987) agreed with Barrie and Paulson on three of the four categories, added two other categories and

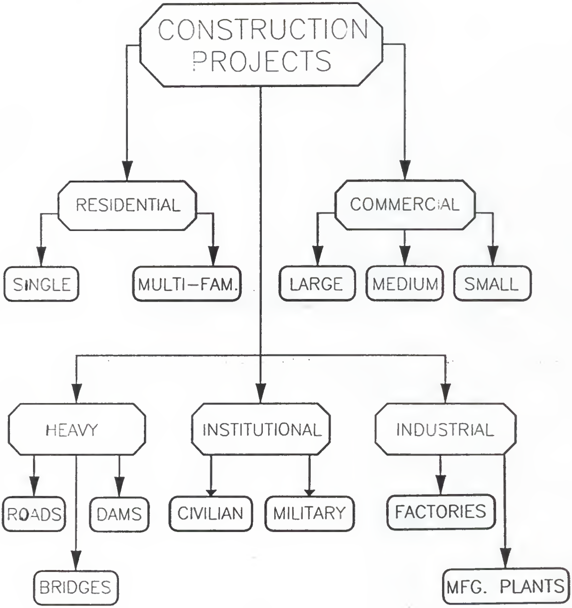

Figure 1. Categories of Construction Projects

concluded that construction projects may be broken down into the following five major categories illustrated in Figure 1.

1. Residential construction consists of single family housing and multi-family housing projects such as apartments and condominiums;
2. Heavy construction consists of earthmoving projects such as roads, bridges, dams, hydroelectric projects, etc.;
3. Commercial construction consists of projects such as office buildings, shopping centers, shopping malls, automobile dealerships, gas stations, sports complexes, hospitals, nursing homes, schools, correctional facilities, parking garages, hotels, etc.;
4. Institutional construction consists of military and civilian projects such as dormitories;
5. Industrial construction consists of heavy mechanical and piping type projects such as manufacturing plants, process plants, factories, etc.

Phases Within a Construction Project

In order to facilitate the cost estimating, design and management processes, it is customary within the construction industry to break a construction project down into either the Twelve "Uniformat" divisions or the sixteen Uniform Construction Index (UCI) divisions. As stated by Means (1986):

> Twelve "Uniformat" divisions organize building construction into major components that can be used in Systems estimates. (p. 5)

These Uniformat divisions are listed below

Division 1 - Foundations

Division 2 - Substructures

Division 3 - Superstructure

Division 4 - Exterior Closure

Division 5 - Roofing

Division 6 - Interior Construction

Division 7 - Conveying

Division 8 - Mechanical

Division 9 - Electrical

Division 10 - General Conditions

Division 11 - Special

Division 12 - Site Work.

Although the twelve Uniformat divisions are often used in systems estimating, most construction specifications, project manuals and cost reference books use the sixteen Uniform Construction Index (UCI) divisions as adopted by the Construction Specifications Institute, Inc. (CSI) to provide a standard of uniformity for organizing the various components of a building. The sixteen divisions are

Division 1 - General Requirements

Division 2 - Site Work

Division 3 - Concrete

Division 4 - Masonry

Division 5 - Metals

Division 6 - Wood & Plastics

Division 7 - Thermal & Moisture Protection

Division 8 - Doors, Windows & Glass

Division 9 - Finishes

Division 10 - Specialties

Division 11 - Equipment

Division 12 - Furnishings

Division 13 - Special Construction

Division 14 - Conveying Systems

Division 15 - Mechanical

Division 16 - Electrical

Walker (1986) pointed out that:

> The CSI system has met with industry and professional acceptance and is the generally accepted form for specifications today. (p. 3.21)

Besides the difference of the number of divisions in each of the two systems, another major difference is that in the "Uniformat" system, a component may appear in more than one division, while in the UCI format, each component usually appears in the division to which it belongs. For example, in the Uniformat system, concrete can be found in Division 1 (Foundations), Division 2 (Substructures), Division 3 (Superstructure), Division 5 (Roofing) and Division 12 (Site Work); whereas in the UCI system, all the concrete can usually be found in Division 3. Both of the systems reviewed here serve the purposes for which they were intended. However, they are

not suitable for this study because contractors do not usually keep accident records to those levels of detail. Therefore the following six major phases will be used in this research.

1. Site Work
2. Substructure
3. Superstructure
4. Roofing
5. Exterior Cladding
6. Interior Work

The Causes of Construction Accidents

When there is a major catastrophe, such as the crash of a jumbo airliner or the release of radioactivity from a nuclear plant, the event attracts attention and public concern because it usually impacts individuals outside the airline and nuclear industries. Construction accidents, on the other hand, often occur individually and the victims are usually employed within the industry. As a result, accidents in the construction industry, unless it is a major catastrophe as the one that killed 28 workers at the L'Ambiance Plaza in Connecticut in 1987, often receive very little attention from the general public in spite of the high number of fatalities each year. As asserted by King and Hudson (1985):

> Construction accidents, by their nature, usually occur singly, and to those employed within the industry. As a result they attract only a fraction of the public concern which is usually felt about most catastrophes. (p. i)

What then are the causes of accidents in the construction industry? King and Hudson (1985) gave the following reasons for the poor safety record of the construction industry:

a). the minimal outlay required to start and carry on a business and the concomitant ease with which it can be liquidated;

b). the small size of most construction firms;

c). the acquisition of work by competitive tendering (bidding);

d). the extensive use of subcontract and self-employed labor-only subcontractors;

f). the use of transient labor;

g). the temporary nature and duration of work sites;

h). the seasonal nature of the employment;

i). effects of weather, including spells of long working hours to compensate for bad weather; and

j). high labor turnover.

All of the above constitute valid factors that can undoubtedly contribute to the high number of construction accidents. However, the major causes of construction-related accidents can be traced to the following

1. The unique nature of the industry
2. Human behavior
3. Job site conditions
4. Unsafe methods, equipment or procedures and
5. Acts of God.

The Unique Nature of the Industry

The construction industry has many unique characteristics that contribute significantly to the occurrence of accidents. Examples of such unique characteristics are

Transient workforce. The industry uses, for the most part, a transient workforce that is often hired through a trial and error process and laid off upon the completion of various phases of a project or upon the completion of the entire project. This makes it difficult to maintain continuity in a safety program and to keep a constant workforce of safety-indoctrinated workers for long periods.

Variable hazards. Hazards in the construction industry vary depending on such factors as type of project, phase, location, design, size etc. This often makes regular general safety plans obsolete or ineffective.

Harsh environment. Unlike workers in the manufacturing and other industries, construction workers usually have to work in an open environment where they are often exposed to hostile and drastic changes in climatic conditions.

Strenuous physical tasks. The physical construction process involves hard manual tasks that often require workers to work in cramped and unnatural body positions, at great heights and in limited spaces.

Human behavior. Human behavior and unsafe acts by workers can be blamed for the majority of industrial accidents. As determined by Levitt and Samelson (1987):

> 80% of industrial accidents involve an unsafe act by a worker. (p. xv)

Therefore, the human element, including failure to observe safety rules, cannot be overlooked as a contributory factor towards the number of accidents in an industry where the workers frequently change from one project to another at comparatively short intervals.

Job site conditions. Unsafe conditions at construction sites, such as poor housekeeping and violations of OSHA regulations and/or building codes, can lead to accidents.

Unsafe methods, equipment or procedures. Construction is an industry where the general contractor is often selected based on the submission of the lowest bid. In addition, most contractors are constantly striving to meet deadlines and schedules that are sometimes unrealistic. Therefore in order to perform the work as economically as possible, maintain estimated profits and meet deadlines and tight schedules, field employees of contractors are often forced by pressure and circumstances to use methods, equipment or procedures that may be fast and economical, but sometimes unsafe.

Acts of God. Natural phenomena such as lightning, earthquake, etc. can cause accidents. The percentages of accidents currently contributed by each of the above characteristics are not clear. However, Anderson (1975) contends that in the late 1970s:

> unsafe conditions were the cause of 12%-20% of all accidents; unsafe acts were the cause of 70%-86% of all acci-

dents; and acts of God contributed between 2%-10% of all accidents. (p. 15)

Safety Regulations in the Construction Industry

Safety in the construction industry is regulated by

1. Building Codes, and
2. The Occupational Safety and Health Administration Act.

The purpose of a building code is to safeguard life, health and public welfare and protect property by regulating and controlling the design, construction, remodelling, repair, equipment, use and occupancy, maintenance and demolition of all building structures.

The most popular code, the Standard Building Code "is dedicated to the development of better building construction and greater safety to the public and uniformity in building laws; to the granting of full justice to all building materials on a fair basis of the true merits of each material; and to development on a sound economic basis for the future growth of our nation through unbiased and equitable dealing with building construction" (p. ii).

Building codes are enforced in each locale by a building official who is in charge of the local "Building Department". This is the department which issues permits for construction. A building official enforces the provisions of a building code with the assistance of authorized representatives known as

inspectors who have the authority to issue stop work orders on any building or structure if it violates the provisions of the code or if construction is being accomplished in a dangerous or unsafe manner. The building official or his representatives conduct inspections at various intervals of construction, and a final inspection prior to the issuance of a certificate of occupancy.

The Occupational Safety and Health Act went into effect on April 28, 1971 and covers employees of all industries (including federal government employees). The only exceptions are those employees who are covered by other safety programs such as the Atomic Energy Act of 1954 and the Coal Mine Health and Safety Act of 1969. The construction industry is regulated by OSHA Safety and Health Standards 29 CFR 1926. The purpose of OSHA is to

1. set and enforce safety and health standards in order to provide workers with safe and healthy environment to work in;
2. encourage employers and employees to reduce workplace hazards, and to implement existing, new or improved safety and health programs;
3. provide for research in Occupational Safety and Health in order to develop innovative ways of dealing with Occupational Safety and Health problems;

4. establish a "separate but dependent responsibilities and rights" for both employers and employees in order to achieve better safety conditions;
5. maintain a reporting and recordkeeping system to monitor occupational injuries and illnesses;
6. establish training programs to increase the number and competency level of occupational safety personnel; and
7. provide for the development, analysis, evaluation and approval of occupational safety and health programs at the State level.

Current Safety Analysis Methods

The development of a model concept for predicting accidents on construction sites necessitated a review of the literature for general safety analysis methods that have been developed in the past. Hammer (1985) describes three methods: Preliminary Hazard Analysis (PHA), Failure Modes and Effects Analysis (FMEA), and Fault Tree Analysis. A brief review of these three methods is presented below.

Preliminary Hazard Analysis

As the name implies, this is usually an initial study to determine what hazards might be present, whether they can be eliminated entirely, and if not, the best way to control them. It is generally used in a systematic process to determine the causes, effects and deterrents of hazards.

Failure Modes and Effects Analysis

This method was derived from reliability engineering (failure modes and effects analysis) and is used to analyze equipment in order to determine what the effects of failures of individual components might be. As Hammer (1985) pointed out:

> The method would probably not be used to a great extent by an occupational safety engineer, but an occasion might arise in which it would be highly desirable to determine whether or not the manufacturer of a piece of industrial equipment to be purchased and installed had such an analysis made. (p.487)

Fault Tree Analysis

This method was developed by Bell Laboratories in 1961 for the U.S. Air Force when they became concerned with "potentially catastrophic events which could occur with the Minuteman missile then being developed by Boeing". The method is used to compute the probabilities of events. Even though it is still used by the Air Force to determine probabilities of mishaps in complex systems or operations, it can also be used to logically analyze the possibilities of potential hazards. Of the three methods of analysis reviewed, the fault tree analysis appears to be relevant to this study because it is a system of making a detailed analysis of failure or potential failure by drawing a logic diagram that traces all the events that might have led to an undesired event. To use this method, first, an undesired event (top event) is selected (e.g. severe injury to the leg of a bulldozer operator on a

construction site). Then an identification of all the ways in which this accident could occur is made by reasoning and visualizing backwards. Each contributing factor or cause is listed, studied and analyzed to determine how it can possibly cause the selected injury and to eliminate the less significant ones. Future accidents can then be prevented by eliminating the causes that can contribute to the accident. This method is based on the Boolean logic and according to Hammer (1985)

$$K = B + CD,$$

where

K = Top Event (the selected injury)

B, C & D = Events that can cause K to happen. (p. 562)

The strength of this method is that it can be used for investigating accidents (after they have occurred) in the commercial construction industry. Its main weakness is that it can only be used for predicting commercial construction site accidents after an accident has been identified--i.e., it still requires the use of another technique to determine the probability of a specific accident or injury occurring before the logic can be drawn. This method can therefore be used effectively when the type of accident to be expected on a construction site can be predicted.

Current Accident Prediction Models

Although the literature did not reveal specific models for predicting accidents at construction sites, it revealed the following related models:

Accident Cost Estimating Model

This model was developed by T. Craig Sinclair on behalf of the Robens Committee on Health and Safety in the United Kingdom to estimate the cost of accidents in the Agriculture industry. According to King and Magid (1979) the cost of accident per worker is

$$C_A = R_D \times (A_{SD} + A_{OD}) + R_S(A_{SS} + A_{OS}) + R_O(A_{SO} + A_{OO})$$

where C_A = annual cost per worker;

R_D = annual risk of death per worker;

R_S = annual risk of serious injury per worker;

R_O = annual risk of other injury per worker;

A_S = subjective element of cost} The second subscript D, S or O stands for Death, serious injury and other injury.

A_O = objective element of cost. (p. 29)

The strength of this model is that it can be adapted for use in the calculation of costs related to building construction accidents. However, it cannot be used for predicting accidents.

Contractors Insurance Premium Rating Model

This is used by Insurance carriers to determine the experience modification rating (EMR) for contractors, based

on the loss history of contractors. An example of this type of model is

Rating = Basic + Losses + Trend & Development Factors + Loss expense + Taxes

where

Basic = Cost plus factor representing insurance company expenses, profit, etc.

Losses = A ratio of a contractor's losses for the preceding three years

Trend and Dev. Factors = Cost of inflation, increases in cost of development, repairs, reserves, etc.

Loss = Expenses incurred by the insurance company in relation to a loss sustained by a contractor.

This model is used by insurance companies to forecast what premiums to charge contractors. It is not designed for use in predicting accidents.

<u>The Safe Job Observation Technique</u>

This method, according to Mr. Ron Stanovich of NIOSH, involves the following steps:

a). going out to construction sites periodically to observe construction workers, safe job practices and unsafe job practices;

b). following up with these observations on the same sites "over a period of time";

c). using the information obtained to predict accidents on future projects.

For instance, if one were to observe eight workers on scaffolding throughout the duration of a 15-story project without safety belts and two of them fell and died as a result, then on the next project if several workers are seen working on high scaffolding then two deaths can be predicted for that project. This does not appear to be a scientifically valid technique since conditions and other factors vary considerably form one project to another.

Safety Sampling

Safety sampling has four main steps. Step 1 is developing a code for the most common unsafe acts. Step 2 involves an observer walking rapidly through an operation and observing each employee quickly. If an employee is seen working safely, it is recorded as one safe observation. If an employee is seen to be acting unsafely, the code number is noted and recorded as an unsafe act. Step 3 is to validate the sample statistically to determine whether there are enough observations to constitute a representative sample. According to the National Safety Council (1980) the validation is done with the formula

$$N = \frac{4(1 - P)}{Y^2(P)}$$

where

N = total number of observations required

P = percentage of unsafe observations

Y = desired accuracy. (p. 86)

Step 4 is to prepare a report for management showing each supervisor's rating expressed as a percentage of safe to unsafe acts.

This method appears to be an excellent indicator of supervisory performance and also an excellent motivator of supervisory personnel in a factory setting. However, it does not appear as if it can be used to predict building construction site accidents.

Accident Prediction Model for Signalized Intersections

This is a model developed in 1988 by the Institute of Transportation Studies at the University of California, Berkeley for the California Department of Transportation (CALTRANS). Under a two-year project funded by CALTRANS, accident prediction models were developed by Lau and May (1988) for signalized road intersections based on a Traffic Accident Surveillance and Analysis System (TASAS).

According to Lau and May (1988), TASAS was implemented in 1973 by CALTRANS and the State Highway Patrol of California, and describes every segment of the State Highway System including the geometric design, control measures, traffic demand and the resulting accident experience. TASAS consists of two major files. The first file contains information on the geometric design (such as type of intersection, left turn channelization, right turn channelization, number of lanes, divided and undivided median); control measures (such as multiphase fully actuated traffic controllers, two-phase

pretimed traffic controllers, etc.); traffic demand; and other details of roads such as intersections, highways, ramps, etc. The second file contains information on individual accidents and a record for each of the 122,000 accidents that occurred at the 2500 intersections, such as the type of accident, date of occurrence etc.

The goal of the project was to develop a set of models that can be easily used by CALTRANS professionals to estimate accident statistics at signalized intersections given specific factors such as geometric design elements, traffic control measures, traffic demand patterns, individual accident history and other factors. The data base used for the study included information on 122,000 accidents that occurred at 2500 signalized intersections under the jurisdiction of CALTRANS from 1979 through 1985. From the above data base, the following two prediction models were developed:

Injury accident prediction models

Injury accidents were defined as those accidents in which one or more persons involved are slightly to seriously injured. Using the factors of traffic intensity, and intersection characteristics, the following equation was developed by Lau and May (1988) as the base model for predicting the number of injury accidents per year based on estimates of slope and intercept obtained by regression analysis:

$$FIACCYR = 0.6186 + 0.1691(MVYR)$$

where

FIACCYR = Forecasted number of injury accidents per year;

0.6186 = the estimate of intercept (from regression analysis);

0.1691 = the estimate of slope (from regression analysis); and

MVYR = millions of vehicles entering an intersection per year. (p. X.7)

Property-damage-only (PDO) prediction model

PDO accidents were defined by Lau and May (1988) as accidents in which no person is injured or killed. Again, using the same factors and procedure as the one for predicting injury accidents, the following equation was developed as a model for predicting PDO accidents:

$$FPDOYR = 4.6029 + 0.5142(MVYR)$$

where

FPDOYR = Forecasted number of PDO accidents per year;

4.6029 = estimate of intercept (obtained by regression analysis);

0.5142 = estimate of slope (obtained by regression analysis); and

MVYR = the number of vehicles entering an intersection per year. (p. X.8)

Fatal accident prediction

Fatal accidents were defined as those accidents in which one or more persons involved is killed in the accident or dies within 30 days of the occurrence of an accident. According to Lau and May (1988):

> The number of fatal accidents per year does not have a strong relationship with the MVYR (millions of vehicles per year entering an intersection), so an equation like the above formulae was not constructed. Instead, a concept of system risk was formulated, and a bedrock value of 0.018 fatal accidents per year was derived. (p. X.8)

Conclusion

The literature indicated the high number and cost of construction related accidents necessitates the need to find innovative techniques to make safety programs more effective in order to prevent accidents. For instance, the indication that the number of injuries and fatalities over the years has shown little or no reduction may reflect the fact that existing safety programs need to be made more effective. From the review of the literature, it can be concluded that there are a lot of general safety programs and methods of analysis. Preliminary research indicated that there are no definitive existing scientific models for predicting accidents at commercial construction sites. However, since there is often a lag in time between when models (and for that matter, any scientific work) are developed and when they are published in the literature, the search for any existing models considered

sources other than the literature. These sources included the major construction organizations and construction related research centers in the nation all of whom affirmed the fact there are no existing building construction accident prediction models, but expressed the need for the development of such models. The sources contacted and the responses received are summarized below.

<u>The American Society of Civil Engineers</u>, (ASCE) New York, N.Y. (Construction Division). Phone (212)705-7498.

Mr. Tony Baez indicated that he was not aware of the existence of any such models.

<u>The American Society of Safety Engineers</u> (ASSE). Phone (312)692-4121.

Mr. Bill Larson, who said he had over 40 years of experience in construction safety indicated that the ASSE was not aware of any such models even though he felt they are needed.

<u>The Associated General Contractors of America</u> (AGC--the safety division), Washington, D.C. Phone (202)393-2040.

Ms. Sandy Solowiej stated that the AGC was not aware of the existence of such models.

<u>The Associated Builders & Contractors</u> (ABC), Washington, D.C Phone (202)637-8800.

Mr. Tom Vorholt of the safety division indicated that the ABC was not aware of any models for predicting accidents on building construction sites.

Alexander & Alexander Inc., Construction Division (Risk Identification & loss forecasting), Atlanta, Georgia Phone (404)266-0560.

Mr. Gary O'neal indicated that they were not aware of any such models. However, they like other insurance carriers had a formula for calculating the loss ratio of contractors and insurance premium rates for contractors.

Center for Excellence in Construction Safety, Dept. of Civil Engineering, West Virginia University, Morgantown, Phone (304)293-7607.

Mr. David Kliwinski indicated that they were not aware of any such models. The center for excellence in construction safety was established in October, 1986 under the auspices of the National Institute for Occupational Safety and Health and has three main objectives:

a). to develop and promote educational materials for academic and nonacademic audiences including the architectural/engineering design community, the construction industry--engineers, contractors, managers and other related parties;

b). to synthesize existing research and develop new ones with the aim of finding innovative solutions to safety problems within the construction industry; and

c). to serve as an information transfer/clearinghouse for matters related to safety in the construction industry.

The activities of the center include: the publication of a quarterly newsletter; incorporation of construction safety elements into undergraduate and graduate courses; development of course materials and instruction on construction safety for academic and industrial users; compilation of state-of-the-art report of past research as well as identification of future research needs; functioning as an information transfer/clearinghouse for construction safety information through its expanding database; and providing outreach services through short courses, training programs and the National Forum on construction safety and Health priorities.

Construction Laboratory Research Council, Washington, D.C. Phone (202)223-8045.

Mr. Bob Gasperow indicated that they were not aware of the existence of such models.

Liberty Mutual Insurance Company (believed to be the nation's largest underwriter of Workmens' Compensation Insurance), Boston, Massachusetts. Phone (800)225-2390.

Mr. Bob Gaznell, Director of the Contracting Division, indicated the insurance industry does not have any models for predicting building construction accidents. He suggested that I contact the Alliance of American Insurers and the Association of Carriers for possible support in the research effort to develop state and regional models.

The National Institute of Safety and Health (NIOSH--the research arm of OSHA), Morgantown, West Virginia. Phone (304)291-4531.

Mr Ron Stanovich stated that his office was not aware of the existence of any such models.

The National Safety Council, Chicago, Illinois. Phone (312) 527-7307. Contacts: Mr. Alan Hoskins (Head of the Council's statistics department); Ms. Elizabeth Lucas of the Product Design section; and Mr. Gary Buerger, Director of the North Florida Safety Council, Phone (904)724-6903.

Mr. Buerger, after contacting his headquarters in Chicago, stated that the National Safety Council (an organization which compiles and publishes statistics on all accidents nationwide) was not aware of the existence of any such models. The Council, however, expressed great interest in the development of such a model.

U.S. Army Corps of Engineers, Construction Engineering Research Laboratory (CERL), Champaign, Illinois. Phone (217)373-7240.

Mr. Roger Brauer indicated that the center was not aware of any such models.

The literature search and the survey conducted both indicated that there are presently no known commercial construction site accident prediction models. Even though the literature review revealed numerous studies and reports dealing with construction site safety, none dealt with the

subject of scientifically predicting accidents. There is therefore a need to develop a concept that can lead to a model for predicting commercial construction site accidents.

Of all the models reviewed, the accident prediction models for signalized intersections developed by Lau and May (1988) at the Institute of Transportation Studies, University of California, Berkeley for the California Department of Transportation were the most relevant to this study. Even though the Lau and May models were developed specifically to predict traffic accidents and not building construction site accidents, some of the concepts derived are relevant to this study and will be adopted to form a basis for designing the model approach.

CHAPTER 3

RESEARCH METHODOLOGY

Introduction

The objective of this research is to develop a model approach that can help the construction industry to explain accidents as a function of various influencing factors (independent variables) and thereby predict future accidents at construction sites, given a set of parameters. The prediction aspect of the proposed concept can be achieved through modelling.

Modeling is defined as a process for determining, defining and explaining the relationships among a set of variables. Models usually involve two groups of variables. They are

1. Dependent Variable, sometimes also referred to as response variable, is defined as the variable to be predicted from a given set of variables.
2. Independent Variables, also sometimes referred to as predictor variables, are the other variables that are to be evaluated in a research project.

Considering the objective of this dissertation, the emphasis in this research was not placed on the development of new and sophisticated statistical or mathematical theories, but rather on the application of basic existing statistical tools and techniques that can facilitate the development of simple models. This chapter presents the details of the important tools and techniques used in developing a model approach for predicting the number of accidents.

Criteria for Development of Model Approach

It is anticipated that the concept will be used by construction loss control and safety experts, construction field personnel as well as others with very limited or no mathematical and statistical background. Therefore one of the initial steps in the development of the concept was to establish important criteria that can help accomplish the objective of this study. The major criteria developed and established in the research effort to develop the model concept were

1. Simplicity

   The main intended users of the concept are field superintendents, project managers, safety directors, insurance personnel, etc. Therefore the concept must be simple and easy to follow, implement and use.

2. Common Parameters

   There are so many types of projects and numerous intangibles associated with building construction projects. Therefore in order to develop a concept that will have

practical application, it was important to select parameters that will be common to most building construction projects.

3. Data Availability

The issue of accidents at construction sites is a very sensitive one within the industry. In addition, the literature review yielded no data from previous research of this nature. As a result, some of the highly desirable data and parameters are not readily available. Therefore extreme caution has to be exercised during the development of the concept to ensure that data for the selected factors are available.

4. Application

The literature search conducted for this study confirmed the lack of the existence of building construction accident prediction models. It therefore became evident that the construction industry would benefit most from a methodology which can lead to the derivation of construction site accident prediction models.

5. Feasibility

This research effort is unfunded at this time. It was therefore logical to consider a concept that can be realistically developed with minimum financial resources.

6. Significance

For the model concept to be useful to the building construction industry, it was important to determine if it had the potential of playing a significant role in improving the poor safety record of the construction industry. All indications (based on discussions and interviews with safety professionals, contractors and insurance carriers) were that, when developed, such a concept can play a fairly significant role to help reduce the number of accidents at construction sites. Eventually this (the reduction of the number of construction site accidents) can lead to the reduction in workers' compensation insurance rates, which can then lead to lower cost of construction.

Statistical Considerations

In statistical terms, the purpose of this research is to determine the relationship between a number of independent variables and the number of accidents on a construction site. This can be done by expressing the dependent variable, the number of accidents, as a function of the various factors (independent variables) that have been known to influence accidents at construction sites. Once the relationship between the dependent variable and the independent variable is established as a mathematical expression, it can then be used, in the future, to predict the number of accidents to be expected

on specific construction projects when given the influencing factors peculiar to that project.

The following are some of the statistical techniques that can be used to analyze the data to be collected for this study:

Regression Analysis

This can be used to determine the extent, direction and the strength of the relationship between several independent variables and a dependent variable. For example, it can be used to determine the relationship between the number of accidents that can be expected of a contractor and certain independent variables such as the size of the project, type of structure, duration of the contract, experience of the contractor, etc.

Discriminant Analysis

This can be used to determine how one or more independent variables can be used to discriminate among different categories of a dependent variable. For example, in the context of this study, this technique can be used to determine to what extent the number of years in business, number of accidents on previous projects and the annual dollar volume of contracts can be used to discriminate between contractors who may or may not have accidents on a certain proposed project.

Analysis of Covariance

This technique is used to analyze the relationship between a dependent variable and one or more independent

variables, while controlling the effects of one or more independent variables. Within the context of this study, analysis of covariance can be used to determine whether or not one contractor is more likely to have a certain number of accidents, than other contractors in a group being studied, in performing a certain size contract based on just the annual volume of the firm, after controlling the effects of the other independent variables.

It should be pointed out that regression analysis is a general technique that can be used for several types of statistical analysis and with all kinds of variables. Other techniques such as the analysis of covariance are considered by most statisticians to be special cases of regression analysis, and even though the theoretical bases of regression analysis and discriminant analysis are different, it is possible to perform discriminant analysis using regression analysis. There are two types of regression analysis as illustrated in Figure 2. They are:

<u>Linear Regression</u>

This is a method that is used to define the relationship between two variables and is usually expressed in the form

Y (dependent or response variable)= $\beta_0 + \beta_1 x + \epsilon$ where

β_0 = intercept

β_1 = slope

x = independent (predictor) variable

ϵ = error term

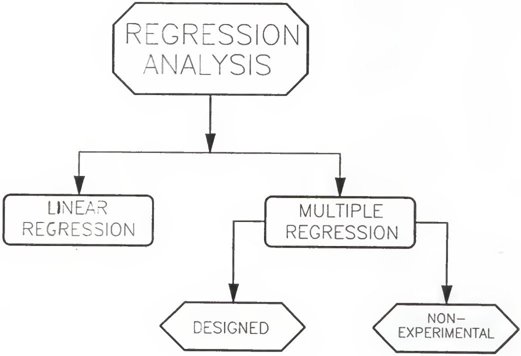

Figure 2. Types of Regression Analysis

Multiple Regression

This is a method for relating two or more independent variables to a dependent variable. It is best applied when the variables are continuous (as opposed to discrete or categorical variables such as type of contractor or type of project or sex of injured worker, where a method known as analysis of variance is normally applied).

Multiple regression can be used in two distinct ways. They are

i). Designed Regression. This is usually used in studies where the levels of the independent variables (such as the amount of medication taken by an injured worker and the number of days between dosages) have been experimentally controlled.

ii). Nonexperimental Regression. This is normally used in studies where a sample of subjects have been observed on a number of naturally occurring variables (such as the experience of contractor in years, annual dollar volume, square footage of a project, etc.) which are then related to some outcome of interest (dependent variable).

Multiple regression is usually expressed in the form:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3, \ldots, \beta_k x_k + \epsilon$$

where β_0, β_1, β_2, $\beta_3, \ldots, \beta_k$ are the regression coefficients that need to be estimated, and x_1, x_2, $x_3, \ldots, x_k$ are separate known or given independent variables.

In a general linear regression model, the dependent variable (for example, the number of accidents to be expected) is represented by Y; the independent variables (for example, the size of a contractor, contract amount, the number of stories, the size of the project, etc.) are represented by the Xs; Parameter estimates are represented by the βs; and the random error term, which accounts for all factors associated with the model that cannot be predicted or explained, is represented by ϵ.

Although the other statistical tools described (as well as others not described) may be used for analyzing the data for this study, nonexperimental regression analysis appears to be the best tool to use for the following reasons:

1. It can be applied in a wide variety of situations.
2. It is the simplest method to use when the nature of the data to be collected and analyzed is considered.
3. Many other more complex statistical techniques can be better understood, once regression methods are understood.
4. This study will involve defining a population of interest (contractors in North Florida who have had accidents on commercial construction projects between 1983 and 1989) and drawing a sample in order to explain the variation in the dependent variable by one or more independent variable.

General Research Design

The study was conducted in six phases as illustrated in Figure 3. Each of the six phases is discussed below:

Phase I--Factor (parameter) identification

In order to develop the model, the dependent variable and independent variables were determined. The dependent variable (Y) was defined as the number of accidents to be expected on a construction site. Independent variables (factors--X) that can influence the occurrence of accidents at construction sites were identified. Initially, the factors identified were

a). Phase of project;

b). Size of project;

c). Type of contractor; and

d). Season of the year.

Then other factors that have been known to contribute to the occurrence of construction site accidents were considered. These included the experience of workers, health of workers, demography of workers, worker activities and status of equipment. However, after reviewing data furnished by the Florida Department of Labor statistics and conducting initial interviews with contractor personnel, it became apparent that there was need to make a distinction between desirable factors

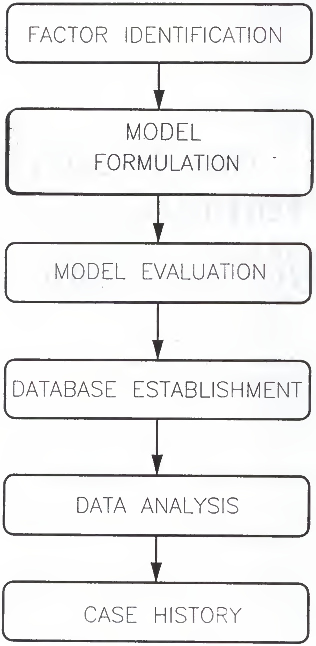

Figure 3. Major Phases of the Study

that are difficult or impossible to obtain from the population of interest and those which are readily available and can be collected for use in this study. After visiting and meeting with several contractor safety personnel, considering the objective of the research and the statistical techniques chosen for the study, the following were selected as the most relevant and independent variables for which the data required can be obtained:

a). Experience of contractor;

b). Size of contractor;

c). Type of project;

d). Starting date of project;

e). Square footage of project;

f). Number of stories in project;

g). Contract amount;

h). Type of structure (reinforced concrete, precast concrete, masonry, wood, etc.);

i). Total number of accidents on project; and

j). The number of each type of accident included in the total number of accidents on each project.

<u>Phase II--Model Formulation</u>

Two models were hypothesized based upon the established criteria for developing the model approach, examination of the construction process, data available, the selected factors and the selection of the appropriate standard statistical analytical techniques previously discussed. These models are

I. <u>Model number one</u>

$$Y = \mu + [P_i + S_j + T_k + W_l] + [(PS)_{ij} + (PT)_{ik} + (PW)_{il} + (ST)_{jk} + (SW)_{jl} + (TW)_{kl}] + [(PST)_{ijk} + (PSW)_{ijl} + (PTW)_{ikl} + (STW)_{jkl}] + \epsilon_{ijkl}$$

where

Y = estimated (average) number of accidents to be expected on a construction project

μ = Overall Mean (the number of accidents that is expected to occur on a project, assuming that none of the independent variables are present)

P = Phase of Project

S = Size of Project

T = Type of Contractor

W = Season (Time of the year)

ϵ = Error Term (accounts for anything that cannot be explained in the model--such as management characteristics of contractors, human behavior and all high order interactions among independent variables--and is usually negligible).

$i = 1,\ldots,6$

$j = 1,\ldots,3$

$k = 1, 2$

$l = 1,\ldots,4$

Model number one was based on the following nomenclature:

P = Phase of a project with six levels ($P_1,\ldots,P_6$) where

P_1 = Sitework

P_2 = Substructure

P_3 = Superstructure

P_4 = Roofing

P_5 = Exterior Cladding

P_6 = Interior Finishes

S = Size of a project with three levels $(S_1,\ldots,S_3)$
where

S_1 = Small

S_2 = Medium

S_3 = Large

T = Type of Contractor, with two levels (T_1 & T_2), where

T_1 = General Contractor

T_2 = Subcontractor

W = Season, with four levels, where

W_1 = Winter

W_2 = Spring

W_3 = Summer

W_4 = Fall

II. Model number two

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9 + \beta_{10} x_{10} + \beta_{11} x_{11} + \beta_{12} x_{12} + \beta_{13} x_{13} + \beta_{14} x_{14} + \epsilon$$

where

Y = The number of accidents to be anticipated

β_0 = Overall Mean

x_1 = Square footage

x_2 = Number of stories

x_3 = Contract Amount (in millions)

x_4 = Contract duration (in months)

x_5 = Experience of injured worker with firm

x_6 = Experience of general contractor

x_7 = { if steel structure

x_8 = { if concrete structure

x_9 = { if masonry structure

x_{10} = { if wood structure

x_{12} = { if combination structure

x_{13} = { if urban location

x_{14} = { if suburban location

ϵ = Error Term

Phase III--Evaluation of Models

Both models were examined for adequacy, considering the availability of the data for the selected parameters. Then independent variables that were highly correlated were either combined or eliminated as necessary in order to avoid problems with the preciseness of the proposed model. Based on this evaluation, and the nature of the available data, it was determined that the second model formulated above would be the most appropriate one to achieve the objective of this research.

Phase IV--Data Base Establishment

The collection, storage, management and access of data on past commercial construction site accidents are very critical to the development of the proposed concept. Therefore a database was created to handle the large quantities of data on past accidents collected from contractors. Each record in the database consisted of a single observation of a commercial construction site accident. A data collection form was designed to facilitate the collection of data from contractors. A sample of the preliminary form designed for this purpose is presented in Appendix A. Details of the data collection scheme used are discussed in the next section.

For the purpose of this study, information on commercial construction projects, obtained from the chosen contractors in the population of interest were collected and stored in an ASCII text file using the Wordperfect software. Basically, the information in the database were divided into three major parts, namely:

Contractor characteristics data

This includes the experience of each of the contractors chosen for the study (expressed by the number of years in business) and the size of each contractor (expressed the average dollar volume for the past five years). There is one record per project, and each record is denoted by an identity number.

Project characteristics data

This describes the details of each project in the database and includes information such as the square footage, the number of stories, the starting date, duration and contract amount of each project.

Individual project accident data

This includes the total number of accidents which occurred on each project and the number of each type of accident involved. No personal information or the identity of the contractor owner, project or the injured workers were kept in the data base system. The latter was necessary in order to protect the identity of the contractors who consented to participate in the study and achieve the anonymity that the researcher had promised those contractors.

In order to facilitate the creation of the database, subsequent statistical analysis and the development of a model, the data was coded as follows:

A. CONTRACTOR CHARACTERISTICS:

DESCRIPTION	CODE
Identification	CONID
Experience	CONEX
Size	CONSIZ

B. PROJECT CHARACTERISTICS:

DESCRIPTION	CODE
Type of Project	PROJ
Contract Duration	DUR

Starting Date	STDAT
Square Footage	PROSF
Number of Stories	PROSTO
Contract Amount	PRAMT
Type of Structure	STRUCT

C. INDIVIDUAL ACCIDENT PROJECT INFORMATION:

DESCRIPTION	CODE
Total Number of Accidents	TOTAC
Types of Accident	
Struck against	STRUG
Struck by	STRUB
Caught in, under, between	COTIN
Fall on same level	FALSAM
Fall to different level	FALDIF
Overextension/bodily reaction	OVEXT
Contact with temperature	COTEMP
Contact with toxics	COTOX
Contact with Electricity	CONEL
Stepped on	STEPD
Cut by	CUT
Foreign object in eye	FOREYE

The description and content of each field in the database are illustrated in Table 6.

Phase V--Data Analysis

The data stored in the database created in phase IV was analyzed using the Statistical Analysis System (SAS),

Table 6. Field Description and Content of Database

CARD COL.	DESCRIPTION	NAME OF VARIABLE
1 -3	Contractor Identification	CONTR
5 -6	Contractor's Experience	CONEX
8 -10	Size of Contractor	CONSIZ
12-13	Type of Project	PROJ
15-16	Project Duration	DUR
18-21	Project Start Date	STDAT
23-25	Project Square Footage	PROSF
27-28	Number of Stories	PROSTO
30-34	Contract Amount	PRAMT
36	Type of Structure	STRUCT
38-39	Total Number of Accidents	TOTAC
	Types of Accident	
41	Struck Against	STRUG
43-44	Struck By	STRUB
46	Caught in, under	COTIN
48-49	Fall on same level	FALSAM
51	Fall to different level	FALDIF
53-55	Overextension/body react.	OVEXT
56	Contact with temperature	COTEMP
58	Contact with toxics	COTOX
60	Contact with Electricity	CONEL
62	Stepped on	STEPD
64	Cut by	CUT
66-67	Foreign object in eye	FOREYE

developed by the SAS Institute Inc. of North Carolina, and then fitted into the proposed model. The model was then validated to arrive at a final model.

Phase VI--Case History

In order to illustrate the model approach in its entirety and how it can be applied in the construction industry, a case history was developed using a sample of 1078 accident data collected from 85 projects in Florida. The case history not only helped to demonstrate the concept, but also revealed potential deficiencies, data collection problems and limitations that may be associated with the implementation of the concept.

Data Collection Scheme

Collection of appropriate and accurate data was very critical in the development of the proposed model concept. At first, data were obtained from the State of Florida Department of Labor and Employment Security, Division of Workers' Compensation. This information included accident data in the building construction industry in four counties in Florida (Duval, Orange, Hillsborough and Pinellas) from 1982 to 1985. An example of the data obtained is presented in Appendix B.

An examination of the data received from the State of Florida showed that it provided the following information:

1. Name of the contractor and his address;
2. The county where the accident occurred;
3. The SIC (standard industry classification) code;

4. The type of injury;
5. The nature of the injury;
6. Part of the body that was injured;
7. The age of the injured worker;
8. Amount of compensation paid to the injured worker;
9. Medical cost of each accident; and
10. The social security number of the injured worker.

It became obvious upon examination of the data obtained from this source that it provided very little information to meet the needs of the factors selected for this study. In addition to this, there were other problems with these data. First of all the data consisted of only those accidents reported to OSHA. The OSHA act requires contractors to record all occupational injuries (regardless of the severity) if they result in death, one or more lost days, restriction of work or motion, loss of consciousness, transfer to another job or medical treatment other than first aid. In addition, employers are required to report to the nearest OSHA office in detail (within 48 hours) any on-the-job accidents which result in the death of an employee or in the hospitalization of five or more employees. Therefore the possibility exists that these data will not include all accidents.

Secondly, at the time of data collection for this study, OSHA had data only through 1985 and had not completed compiling the data for 1986, 1987 and 1988. Thirdly, the OSHA data included meaningful information that can be used to

determine other statistical data such as the frequency of accident, age of injured workers, cost of accidents, etc. However, it lacked the data for two of the three main parts of the database needed for this study--it included neither the characteristics of the contractors (number of years in business, average annual volume etc.) on whose projects the accidents occurred nor characteristics of the projects (square footage, number of stories, duration, contract amount, etc.) on which the accidents occurred. As a result, a decision was made to seek alternate sources of data. Other sources that were contacted included insurance companies, the OSHA Regional office in Jacksonville, Florida and the National Council on Compensation Insurance (NCCI). Examples of the type of data collected by these sources are presented in Appendices B, C and D.

After discussions with several personnel of OSHA, the National Safety Council, insurance companies and construction firms, it became obvious that the most appropriate source for the needed data would be from construction contractors.

Given the research objective, it was apparent that some type of survey would be required to collect the required data. Kerlinger (1973) identified five possible survey research methods:

1. personal interviews;
2. mail questionnaires;
3. the panel technique;

4. telephone interviews; and
5. controlled observations.

Kerlinger (1973) stated that the mail questionnaire method has two primary disadvantages: possible lack of response from sample participants and the inability of the researcher to check the accuracy of the responses received.

Both the panel technique and controlled observations method were found to be inappropriate for this type of study because of the nature of the population (contractors) and data (past accident information) involved. The telephone interview method yielded no results because contractors were reluctant to discuss the sensitive issue of accidents on the telephone. As a result, a combination of personal meetings and interviews was found to be the most effective and utilized. The personal contact enabled the researcher to explain the objective of the research, its potential application and benefit to contractors and personally assure contractor participants of complete anonymity. Personal interviews also permitted a thorough understanding of the safety personnel, safety programs and management organizations of the participants of the study. This provided background material and basis for the validation of the data collection instruments after the first few interviews.

The preliminary data collection form was then revised to facilitate the collection of data from contractors. A copy of this revised form is provided in Appendix E. The first portion

of the form was designed to collect information about a project where accidents have occurred, while the second portion collected specifics of each accident that occurred on that particular project.

Interviews were conducted at the offices of general contractors who were selected at random from the data provided by the Florida Department of Labor. Each contractor was contacted by telephone to explain the study and obtain their consent prior to the visit. After the initial interview, the researcher reviewed the contractor's safety records, specifically the First Notice of Injury report form for each accident that occurred on each project. An example of this form is shown in Appendix F. Project information was obtained either from the project files or the respective project managers for each firm.

Validation of Data Collection Instrument

The validity of the accident data collection form was established by a field test using the first two contractors selected for this study. In interviews, the safety personnel were asked to respond to the form, make suggestions for additions or deletions, and comment on the overall clarity of the form. After reviewing the safety records of the contractors and their comments, the data collection was revised once again. Initially, Section A of the form, project information, was separated as page one. Section B, accident information,

was separated as page two and expanded to collect additional information such as the occupation of the injured worker and length of employment with the contractor prior to the occurrence of the accident. With the validation of the data collection instrument, section A was completed once for each project while section B was completed for as many accidents as occurred on each project.

After the first six interviews and preliminary analysis of the data, the collection form was validated to reflect the objective of the research. A sample of the validated from is presented in Appendix G.

Data Analysis

The Data collected from each of the contractors were stored in a database. The data were the transferred into a SAS dataset for analysis to determine the simple statistics of the data as well as the most significant variables. Once the most significant factors were determined, preliminary models were developed. Several promising models were selected for further evaluation prior to choosing the most appropriate model. The model approach was then demonstrated, using a case his history.

Summary

For this study, the multiple regression analysis method was found to be the most suitable. Accident data collected from selected contractors were analyzed using the Statistical

Analysis System (SAS) to determine whether there was a significant correlation between the dependent variable (number of accidents) and the selected independent variables (parameters) to enable the model to be used in predicting future accidents. The following criteria are critical to the practical application of the concept:

1. It should be simple.
2. It should be statistically reliable.
3. It should be understandable to contractors and other construction or safety personnel.
4. It should be economical to develop and implement.
5. It should use readily available data.
4. It should lend itself to computerization.

It is generally true that the accuracy of prediction models depends to a large extent on the details of the information which serves as the basis on which models are built. However, this relationship should not depend on the complexity of the statistical techniques used. Hence, the method of least squares (multiple regression analysis) was selected in lieu of more complex statistical techniques.

CHAPTER 4

THE MODEL APPROACH

Introduction

The study of construction site accidents in the past has been regarded as a controversial and "slippery" field by many construction experts because occurrences of accidents at construction sites are often highly stochastic in nature. Furthermore, accident data and records often have been found to be incomplete. In most cases, useful and important specific project information (such as the number of stories, square footage, contract amount, etc.) is not a part of the accident report. As a result, safety professionals in the construction industry have been unable to scientifically explain variations in accidents based on a partial list of factors that affect the occurrence of accidents. These partial factors (the part of the body injured, age of the worker, agency of the accident, etc.) have traditionally been related to the injured worker.

This dissertation presents an approach that will enable the construction industry, the government, safety and insurance professionals to establish databases of more useful

and aprpriate accident-influencing factors. These factors can then serve as the basis for scientifically explaining the number of accidents and developing models that can predict the estimated number of accidents to be expected on future commercial construction sites.

Major Phases of the Model Approach

In order to overcome previous problems encountered in the study of construction site accidents, because of the unique nature of the construction industry, and meet the objectives of this research, it was necessary to:

1. Develop an approach that is intuitive and yet reflects the stochastic nature of construction site accidents.
2. Develop a simple and systematic approach that is capable of collecting meaningful and fairly complete data sets and then utilizing such data to develop models for predicting the estimated number of accidents to be anticipated on specific construction sites.

The five-phase approach developed in this research is described in detail below and illustrated with a flowchart in Figure 4.

Phase I: Preliminary Parameter Selection

The first phase of the methodology developed involves the preliminary selection of the response variable as well as factors that have been known to influence the occurrence of

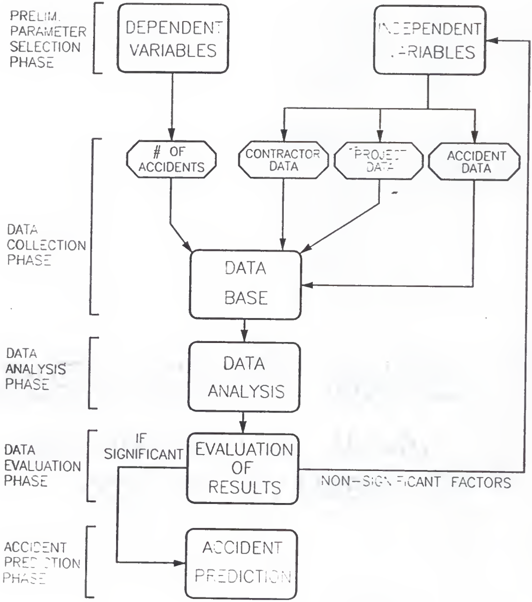

Figure 4. Flowchart of Model Approach

accidents at construction sites. The selection of a response variable is a very important step because it will, to a large extent, determine the structure of the final model. Considering the response variable as the number of accidents to be predicted (expected), the next step is the selection of two groups of data to constitute the independent variables (factors) as illustrated in Figure 5.

The first group of data consists of characteristics of a general contractor that can influence the number of accidents on his sites. Examples of such factors include the size and experience. Size can be based on either the average annual dollar volume of business for preceding five years or the total number of employees. Since the number of contractor employees fluctuates frequently and such data are not readily available, the average annual dollar volume is recommended. Experience can be based on the number of years in business, experience of workers or past accident record. Most contractors do not always keep detailed records of their accident history. Experience of workers can be inaccurate and almost impossible to verify if such information is obtained from the workers themselves. In addition, constant turnover among construction workers makes it a monumental and difficult task for contractors to keep track of the experience of their workers-a chore that most contractors are unwilling to undertake. In order to avoid problems in the collection of the

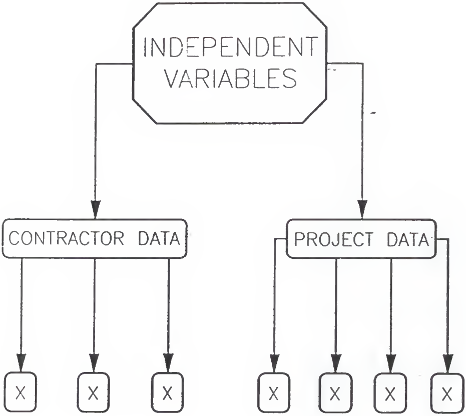

Figure 5. Major Independent Variable Groups

appropriate data, the number of years in business is recommended. These data are usually readily available from contractors.

The second group of data consists of characteristics of projects that can influence the occurrence of accidents. Examples of these data include the type of project (hotel, office building, hospital etc.); geographic location; size (can be based on square footage, number of stories and contract amount); duration (in months or years); type of structure (reinforced concrete, structural steel, masonry, combination of steel and concrete, etc.); average number of subcontractors expected to work on that project; and average number of the general contractor's workers expected to work on that project. Due to contractor recordkeeping problems and other administrative shortcomings characteristic of the construction industry, it is not always possible to get all of these data for each project. However, as a minimum, the following data must be obtained: size of building (square footage), height of building (number of stories), duration of each project (contract period) and contract amount.

After the selection of the factors is completed, but before beginning the next phase, it is necessary to determine the size of the population. In order to make the results of multiple regression analysis statistically valid, the number of data points (number of projects to include in the model), as a rule of thumb, be no less than four times the number of

independent variables (factors) selected for the model to be developed.

Phase II: Data Collection

A database consisting of specific data about accidents that have occurred, over a minimum period of five years, on projects in the desired geographic area must be created. Accident data to be stored in the database should include the following:

Type of accident

The standard OSHA designations--struck against, struck by, fall on same level, caught in or under or in between, overexertion or bodily reaction, contact with temperature or pressure extremes, contact with radiation or caustics & toxic substances, contact with electric current--should be used as a minimum. These designations can be expanded to include others such as stepping on object, foreign object in eye, cut by, etc.).

When each accident occurred

This should include information about the date (month, day and year) and time of day when each accident occurred.

Phase of project where accident occurred

Information about the phase of the project where the accident occurred as well as the specific task being performed by the injured worker and the crew to which he belongs should be collected whenever possible.

Even though information about injured workers (such as the age, height, weight, race, occupation, severity of injury, etc.) is meaningful statistical data that can be collected for the purposes of analysis, these extraneous factors should be excluded from the model for the following reasons:

1. Such data are incidental to the main objective of this thesis. The main objective of this research is to present a systematic approach that can be used to develop models for predicting the number of accidents. Specific and accurate data about a worker, who may be potentially injured, are not only difficult to predict due to the high number of undocumented or unknown random variables associated with the transient workforce of the construction industry, but such data are also secondary to the main issue of interest--the number of accidents.
2. Such data will have very little practical application. In the practical application of the model approach, the general contractor has no control over the age, race, health, etc. of his workers. Contractors normally hire workers based on such factors as their immediate needs, availability of labor, job progress, etc. with little or no consideration about the age, height, weight, race etc. In certain situations, contractors have virtually no choices and are forced by circumstances to hire whoever shows up for employment through a trial and error process. Therefore it would be impractical, for example,

to recommend that a contractor hires only 28 year old workers or only carpenters because statistical analysis indicates that all other age groups or trades have, statistically, a high number of accidents. Besides, the use of these factors to discriminate in the hiring of its workers can be considered illegal. Therefore, even though such factors can be theoretically considered as interesting statistics, their practical application in the model is minimal, at best.

3. Including such data in the database may decrease the level of precision and accuracy of the resulting prediction models. Considering the fact that the objective of this research is to develop a model that can predict the number of accidents, the central issue is the correlation between the dependent variable (the number of accidents) and the primary independent variables. Therefore inclusion of independent variables that are related to each other (such as the age, height, weight, etc. all of which are related to the injured worker) can affect the accuracy of the proposed model. As Ellis (1989) pointed out:

> Using independent variables which are correlated will cause problems with model precision. Therefore model formulation should attempt to avoid the use of highly correlated independent variables. (p. 65)

The collection of data must be accomplished through personal interviews at the offices of the respective contractors. First, contractors should be randomly selected from a list. A list of contractors who have had accidents on their projects can be obtained from the Department of Labor, Bureau of labor Statistics. It is worth noting that this process may not be true random sampling because there is no guarantee that all the chosen contractors will consent to participating in the study and furnishing the required data. In situations where contractors who are randomly selected from a list decline to participate, it may be necessary to select other contractors. In order to assure a good level of contractor participation, a high-ranking officer (such as the president or vice-president) of each of the selected firms should be initially contacted by telephone. The following should be briefly, but carefully and thoroughly communicated during this initial contact:

1. Who the researcher is, institutional affiliation and the nature of the study.
2. The purpose of the study.
3. The potential benefits of its results to contractors.
4. The type of data needed. Emphasis should be made that this is general data that will have no reflection on the firm, its, workers and clients.
5. A guarantee of complete anonymity. Contractors should be promised total anonymity, and that the identity

of the firm, projects, clients, workers will not be revealed to anyone or in any part of the study. It should be carefully explained that all data collected will be aggregated with data collected from other contractors into a statistical model that will have no indication of the source.

6. Assurance of no cost to the contractor. It should be explained that in order not to take up too much of the time of the contractor's employees, the researcher will collect all the data during a visit, if the relevant files can be made available.

7. Contractors should be promised a free copy of the results and findings of the study when completed.

Most of the time, firms that agree to participate will give the researcher the name of a contact person. This is usually the safety officer, director of safety, director of human resources, or in some cases the person in charge of insurance and workmen's compensation matters for the firm. A copy of the data collection form should always be sent in advance to this designated person prior to the visit.

During the visit, the researcher should have adequate data collection forms, supplies, etc. in order not to place any burden on the contractor or his personnel. The contractor information--experience (number of years in business) and size (average annual dollar volume for the past five years)--can usually be obtained by phone prior to the visit. Project

information can normally found in specific project files, or from the firm's project managers. Accident information can be found on the first notice of injury report forms for each project. In cases where these reports are not filed by projects, the researcher should look for other linking data, such as project numbers or name of superintendent.

As a courtesy, it is recommended that letters of appreciation be sent to the first point of contact as well as the designated employees who assisted the researcher during the visit. Samples of such letters are provided in Appendix H.

Phase III: Data Analysis

The data collected from the contractors should be stored in a computer database and analyzed. The Statistical Analysis System (SAS) developed by the SAS Institute of Cary, North Carolina should be used in the data analysis for simplicity and to save time.

First, the raw data should be entered into a micro computer using a database management system (such as wordperfect or lotus 1,2,3) that can output an ASCII text file. The data can be entered into the computer directly from the data collection form. The ASCII file can be dumped into SAS to create a dataset that can be used for all SAS analysis.

Frequency distributions and correlation analysis should be performed using SAS procedures in order to examine the simple statistics, the relationships as well as the strengths and weaknesses of the variables included in the dataset. Then

the data should be analyzed using SAS to determine which independent variables are most significant. This can be accomplished in SAS by determining the R-squared and C(p) values of all the independent variables. The R-squared and C(p) values obtained should be verified using a SAS stepwise regression technique. The goal of stepwise regression is to examine a number of regression equations. By specifying the stepwise procedure, SAS takes all the previously selected independent variables and puts them into a regression one at a time, until all the variables have been added or a specified criterion has been met. The criterion can be one of the following:

a). Statistical significance, such as "there are no more regressors that would be significant if entered" ; or

b). Explanation of improvement in variance, such as "the additional R^2 to be gained by entering the next best regressor is too small to bother with".

There are five different stepwise techniques in the SAS software as illustrated in Figure 6 and described below.

<u>The forward technique</u>

When this technique is specified, SAS begins by finding the best single regressor among all the variables in an equation, and then finds the next best one to add to the first one. This is followed by the next best and so forth until all the variables are added.

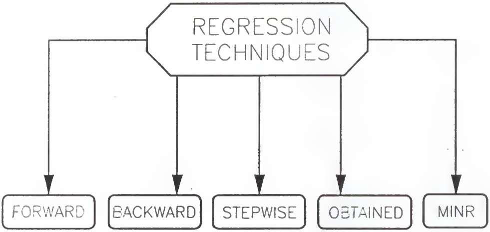

Figure 6. Regression Techniques

The backward technique

With this technique, SAS begins with all the variables in an equation and then drops the worst regressor first, followed by the next worst one and so forth.

Stepwise technique

Under this technique, SAS finds the best regressor among all the variables in an equation, finds the next best one and adds it to the first one and then checks the equation again to see if the regressors remain significant after the new one has been added. This process is continued with each added variable. This technique is therefore very similar to the forward technique, except that SAS adds an additional step in which all the variables are checked again to see if they still remain significant with the additional of each new variable.

Obtained technique

When specified, SAS tries to find the one-variable regression with the highest R^2, then after that it finds the two-variable regression with the highest R^2, and so forth.

MINR technique

This technique is very similar to the OBTAINED technique, except that in this case, SAS tries to select the one-variable regression with the lowest R^2, and so on.

Using the stepwise regression technique, two or three of the most promising models with the most significant variables

should be further examined in order to select the most effective model.

In selecting the most effective model, it is worth noting that the fewer the number of independent variables (factors), the more accurate the model. As Cody and Smith (1987) pointed out:

> Parsimony--less is more in terms of regressors. Another regressor will always explain a little bit more, but it often confuses our understanding of life. (p. 193)

Phase IV: Data Evaluation/Model Development

Based upon an examination and analysis of the experimental data, the trial models should be evaluated for adequacy. If more of the factors selected turn out to be insignificant, or if it is determined that additional factors are necessary, then the researcher should go back to stage I and start over again with new or additional factors. The best model should then be selected using two of the most popular statistical evaluation criteria--the R^2 statistic and the C(p) statistic.

R^2 (the coefficient of determination) measures how much of the variability in the data is explained by a fitted model. R^2 is usually expressed as a percentage and can be calculated as follows:

$$R^2 = \frac{\text{Regression sum of squares}}{\text{Total sum of squares}} \times 100$$

Theoretically a "perfect model" should have an R^2 of 100%. Because it is often unrealistic to expect a 100% R^2 in

non-experimental type of studies, generally, a model with an R^2 of over 40% can be considered as headed towards a level of acceptable significance.

The C(p) statistic, which has been shown to provide a balance between overfitting and underfitting of models, can be used to select a model with the best estimate precision among a group of models. Usually, the best model is obtained at a point where the value of C(p) is close to or approaches the value of P, where P is equal to the total number of factors or variables in a model. For the most part, evaluation of the models can be accomplished by a trial and error process, using the statistical techniques discussed as a guide.

Phase V: Accident Prediction Model

After the effective trial models are selected, they should be carefully examined for any biases and collinearity among the variables in the models. The distribution should be also checked to determine if it is normal or Poisson.

Poisson distribution, named after the French mathematician S.D. Poisson, can be used to determine the probability of X occurrences of accidents per unit time and also applied to problems involving the number of occurrences of a random variable for a given unit area, such as the number of imperfections on a painted wall surface. In order for the

distribution to be considered as Poisson, it must meet certain conditions. As Harnett (1972) pointed out:

> First, it must be possible to subdivide the time interval being used into a large number of small subintervals in such a manner that the probability of an occurrence in each of these subintervals is very small. Second, the probability of an occurrence in each of the subintervals must remain constant throughout the time period being considered. Third, the probability of two or more occurrences in each subinterval must be small enough to be ignored. And finally, an occurrence (or nonoccurrence) in one interval must not affect the occurrence (or non-occurrence) in any other subinterval--i.e., the occurrences must be independent. (p. 120)

If the distribution turns out to be Poisson, then other statistical techniques such as the maximum likelihood estimation, which are more complex than the ones in the proposed concept may be required. However, it is worth pointing out that, under normal circumstances, the distribution of construction site accident data and the associated variables will not meet the criteria for Poisson as outlined by Harnett (1972). The final model selected should have as few variables as possible while giving consideration to the Cp and R^2 statistics.

Summary

The primary objective of this investigation was to develop a systematic methodology that can help the construction industry and other researchers to collect more meaningful construction site accident data. Such data can facilitate the derivation of equations (using basic statistical techniques) for estimating or forecasting the average number of accidents

to be anticipated on future commercial construction projects. The model approach developed in this thesis can also aid future researchers and safety loss control professionals to scientifically determine the most significant variables that can act as contributory factors to the occurrence of construction site accidents.

The approach presented here involves the selection of accident-influencing parameters, the establishment of a database, analysis of the data using the SAS software, evaluation of the data and the derivation of accident prediction models. Using the method of least squares (multiple regression analysis), the base accident prediction model developed can be expressed as

$$\text{ENAPPRO (Y)} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3, \ldots, \beta_k x_k + \epsilon$$

where

ENAPPRO (Y) = estimated (average) number of accidents to be expected per project

β_0 = overall mean (estimated of Y intercept when all the factors are equal to zero) obtained by regression analysis

$\beta_1, \ldots, \beta_k$ = estimate of slope of the straight line of independent variables (change in Y per unit change in X) obtained by regression analysis

$x_1, \ldots, x_k$ = given or known values of independent variables

ϵ = error term (usually negligible--assume that the average value of ϵ for a given value of x is equal to zero).

CHAPTER 5

ILLUSTRATION OF APPROACH--CASE STUDY

Introduction

A concept or a methodology for developing a model that can be used to predict the number of accidents to be expected on a commercial construction site was presented in the preceding chapter. Other chapters before that presented reviews of several schemes and techniques as background knowledge to help in the development of the model approach. Because this concept is offered as a model that can be used by other researchers in the future to develop models for predicting accidents in the construction industry, it is necessary that the concept is demonstrated, using actual accident data. For this study, the demonstration was accomplished with a case study.

In this chapter, important background knowledge previously presented, such as the data collection scheme, statistical considerations, etc. will now be applied in developing an accident prediction model, as a case study.

Objectives

The objectives of the case study were to

a). test the practical application of the model approach developed and present a basic accident prediction model;

b). gain some insight into the basic patterns of accidents at construction sites, given certain specific contractor and project characteristics;

c). determine any potential problems that may be associated with the implementation of the model approach; and

d). provide an opportunity for discussion and exchange of ideas for the conduct of future analysis and research on the development of construction site accident prediction models.

This case study was carried out as an initial step in testing the model approach presented in the preceding chapter using data collected from 85 commercial construction projects and following the five phases previously outlined.

Phase I: Parameter Selection

The first phase of the case study involved the development of a list of preliminary parameters. In order to accomplish this, a population of interest was established. The population consisted of general contractors in four Florida counties (Alachua, Duval, Hillsborough and Pinellas) who have

had accidents on commercial construction project sites between 1983 and 1989. These four counties were chosen because of their close proximity to the researcher and in order to minimize the cost of the research.

After the preliminary design of the study, it became evident that it would be impractical to obtain and work with all the available records within the population of interest. A decision was therefore made to choose a sample, a subset of the population of interest. From this sample, data was collected from 85 commercial construction projects. The information obtained included 1078 accidents, contractor and specific project data from contractors, in the four chosen counties, who had consented to participate in the study and provide the required information. The preliminary independent variables (X_1, X_2, etc.) selected were

a). Contractor Characteristics.

1. Experience
2. Size

b). Project Characteristics.

1. Duration of project
2. Project starting date
3. Project size--square footage
   --number of stories
   --contract amount

Table 7 presents a list of the selected independent variables with an explanation for each one.

Table 7. List of Independent Variables

INDEPENDENT VARIABLE (FACTOR)	EXPLANATION
Experience of contractor	Number of years in business
Size of contractor	Average annual volume for the past five years (measured in dollars)
Duration of project	Construction period per contract (measured in months)
Starting date of project	Contractual start date (month and year)
Size of Project	Number of square feet of building floor area
	Number of stories
	Contract amount (measured in dollars)

The main dependent variable (Y) is the total number of accidents to be expected on a project. Y is the total of the following dependent variables:

Y_1 = NO. of accidents to be caused by 'struck against'

Y_2 = " " " " " " " 'struck by'

Y_3 = " " " " " " " 'Caught in'

Y_4 = " " " " " " " 'Fall on same level'

Y_5 = " " " " " " " 'Fall to different level'

Y_6 = " " " " " " " 'Overextension'

Y_7 = " " " " " " " 'Contact with temperature

Y_8 = " " " " " " " 'Contact with toxics'

Y_9 = " " " " " " " 'Contact with Electricity

Y_{10} = " " " " " " " 'Stepping on object'

Y_{11} = " " " " " " " 'Cut by'

Y_{12} = " " " " " " " 'Foreign object in eye'.

Phase II: Data Collection

After the selection of both the dependent and independent variables, a system to collect the data required was developed. Figure 7 presents a graphic illustration of the data collection system designed for this research.

The first phase of the data collection process was started by obtaining a list of commercial building contractors (SIC Division 1500) within the population of interest, who

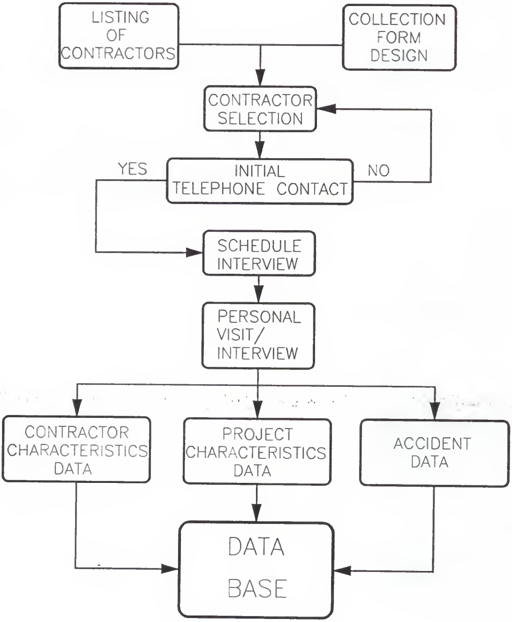

Figure 7. Data Collection Flowchart

have had accidents within the past six years, from the State of Florida Department of Labor and Employment Security, Division of Workers' Compensation. Simultaneously, a data collection form similar to the one illustrated in Figure 8 was developed from the initial data collection form in order to facilitate the collection of data as well as input into the database.

The next step was to randomly select contractors from the above list by either using random tables or other random sampling techniques. Each of the contractors was initially contacted by telephone to seek their consent to participate in this study. During this initial contact, extra effort was made to speak to a high ranking official of the firm such as a president or vice president. These officials were advised by the researcher of the purpose of the study, the potential benefits of the results of the study to their firm and the entire construction industry. In addition to that, the researcher promised, the officials of the construction companies selected, total anonymity of the identity of their respective firms as well as that of their clients and projects. In situations when a contractor chosen by the researcher for the study declined to participate, the researcher went on to select another contractor on the list using the same random method utilized in the original selection process.

If the contractor contacted consented to participate, an appointment for a personal visit and interview was scheduled

COMMERCIAL CONSTRUCTION SITE ACCIDENT PREDICTION

DATA COLLECTION AND ENTRY FORM

A. CONTRACTOR CHARACTERISTICS

1. Experience in years [__________]

2. Size in dollars [$__________________]

B. PROJECT CHARACTERISTICS

1. Duration in months [__________]

2. Starting Date (month/year) [__________]

3. Size:

Number of stories [__________]

Building Area in square feet [____________________]

Contract Amount in dollars [$__________________]

C. ACCIDENT DATA

1. Total Number of Accident on project [_________]

2. Number of each accident type:

Struck against, rubbed or abraded [_____]
Struck by [_____]
Caught in, under or between [_____]
Fall on same level [_____]
Fall to different level [_____]
Overexertion or bodily reaction [_____]
Contact with temperature or pressure extremes [_____]
Contact with radiation, caustics or toxics [_____]
Contact with electric current [_____]
Stepped on object (nail, wire, etc.) [_____]
Cut by [_____]
Foreign object in eye [_____]

Figure 8. Data Collection and Entry Form

immediately with a designated person within the firm. This person, in most cases, was either the safety director of the firm, the director of human resources or a secretary in charge of insurance and workers' compensation matters. The appointment scheduling process required a lot of flexibility on the part of the researcher to accommodate the contractor's plans, schedules, etc.

After the first few appointments, it was determined that the data collection process would be greatly facilitated if the selected contractors were sent, prior to the visit, copies of the data collection forms with specific but simple and brief instructions. During the visits to the offices of the various contractors, projects were randomly selected and data about the contractor, the selected projects and specifics of accidents on the chosen projects collected.

For this case study, a total of 85 projects involving 1078 data points were observed using the method outlined above. The raw data collected from each project was entered into a dynamic database that continued to increase in size as more data was obtained. An ASCII text file was generated, using wordperfect software, to serve as the database. Figure 9 shows an example of the raw data as entered into an ASCII text file to create a database for this research.

```
Options ps=60 nodate;
DATA ACDENTS;
INPUT CONID $1-2 CONEX 3-4 CONSIZ 6-9 TYPE 11-12 DUR 14-15 STDAT
17-20  PROSF 22-26 PROSTO 28-29 PRAMT 31-36 STRUCT 38-39 TOTAC
40-41  STRUG 43-44 STRUB 45-46 COTIN 47-48 FALSAM 49-50 FALDIF
51-52 OVEXT 53-54 COTEMP 55-56 COTOX 57-58 CONEL 59-60 STEPD
61-62 CUT 63-64 FOREYE 65-66;
CARDS;

A 22 22E7  7 11 1186 525E3  1 5567E4 5 60 24 9 7 0 012 0 0 0 0 0 8
A 22 22E7 14  8  187   3E4  5  139E4 5  6  2 1 0 1 0 1 0 0 0 0 0 1
A 22 22E7  5 24  587  86E4  7    9E7 3 85 36 6 6 3 410 6 0 0 0 014
A 22 22E7  5  6  687 143E3  1   38E5 3  7  1 3 0 0 0 0 1 0 0 1 0 1
A 22 22E7  5 13  288   5E5  1  147E5 3 20  2 5 1 0 2 0 0 0 3 0 2 1
A 22 22E7  3 22 1087 122E3  2  436E3 1  8  0 3 0 1 0 3 0 0 0 0 0 1
A 22 22E7  5  8  387   2E5  2  356E4 2  9  0 2 1 0 0 5 0 0 0 1 0 0
A 22 22E7  5 15 1088  28E4  2  329E4 3 11  1 0 1 1 1 1 0 0 0 1 0 5
A 22 22E7  5 14 1188  28E4  1 1482E4 3 15  3 2 2 1 1 1 1 1 1 1 0 1
A 22 22E7  5  8 1188  21E3  3  246E4 6  6  1 0 0 0 0 3 0 0 0 0 1 1
A 22 22E7  5  9  489  12E4  5   78E5 3 13  2 1 4 3 0 1 0 0 0 0 0 2
A 22 22E7  5  6  887  27E3  2  185E4 2  3  1 0 0 1 0 0 0 0 0 0 0 1
A 22 22E7  7  7  687  63E3  1  182E4 1  5  0 0 1 0 0 4 0 0 0 0 0 0
A 22 22E7  5  7  887  64E3  3  333E4 1  7  1 1 1 2 0 1 0 0 0 0 0 1
A 22 22E7  6  7  387  21E4  7   38E5 1  4  0 0 1 1 1 1 0 0 0 0 0 0
A 22 22E7  7  9  687   7E5  1 1777E4 1 13  0 4 2 2 0 4 1 0 0 0 0 0
A 22 22E7  7  9 1287   8E5  1 1438E4 1 18  2 6 1 0 0 7 0 0 0 0 0 2
A 22 22E7  5  8 1187  38E3  1  245E4 5  5  2 0 1 0 0 1 0 0 0 0 0 1
A 22 22E7  7  9  388 201E3  1  776E4 5  7  0 3 1 0 0 2 0 0 0 1 0 0
A 22 22E7  5  8  388  73E3  3  275E4 1  4  1 0 0 0 0 2 0 1 0 0 0 0
A 22 22E7  7  6  688  85E3  1   28E5 5  5  0 1 1 1 0 0 0 0 0 0 0 2
A 22 22E7  5 12  489   8E4  3  813E4 1  3  0 2 0 0 0 1 0 0 0 0 0 0
A 22 22E7 10 14  789  23E4  2  164E5 5  7  1 1 0 3 0 1 0 1 0 0 0 0
A 22 22E7  5 16  290 602E3  7  635E5 1 58 21 7 818 0 0 0 0 0 0 0 4
```

Figure 9. Sample of the Database (ASCII File)

A copy of the database used for the case study is presented in Appendix I. The establishment of a database with pertinent data collected from contractors chosen from the population of interest concluded the data collection phase of the study.

Phase III: Data Analysis

The next phase after data collection was the analysis of the data. The transfer of the raw data from the database created using the wordperfect software to the SAS software was greatly facilitated by the earlier decision to establish the data base in an ASCII text file. As a result no problems were encountered in the transfer of the raw data directly into the SAS software system with an "include" statement. The raw data were then transformed into a SAS data set and analyzed prior to the development of models. The following analyses were performed

1. Frequency distributions
2. Correlation analysis.

Frequency distribution analysis

Tables 8 through 19 present the frequency distributions of the independent variables used in the case study. The frequency distribution tables list the number of occurrences (in each project) of each of the variables used in the data set.

For example in Table 8, the first column indicates the number of occurrences of the variable "STRUG". The second column indicates how many of the 85 projects this variable occurred on. The column labelled "Percent" is the same information as the frequency expressed as a percent of the total number of projects; the columns labelled "Cumulative Frequency" provides a cumulative count of struck against accidents for each pro-ject on which this type of accident occurred and "Cumulative Percent" provides a count of the cumulative percentage of this type accident on each project in the data set.

For instance, line 1 on Table 8 can be interpreted that there were zero "struck against" on 45 projects constituting 52.9% of the total number of projects. Similarly, line 2 shows that there were 17 projects in the dataset where "struck against" accidents occurred once, and so on.

Correlation analysis

Initially, a correlation analysis was performed in order to examine the simple statistics as well the relationships and strengths of the variables included in the data set. Table 18 presents the minimum and maximum values of the variables in the data set.

For example, Table 20 indicates that the minimum annual average volume of the contractors included in the dataset is $14-million and the maximum is $350-million; the minimum

Table 8. Frequency Distribution of "Struck Against" (STRUG) Accidents

STRUG	Frequency	Percent	Cumulative Freq.	Cumulative %
0	45	52.9	45	52.9
1	17	20.0	62	72.9
2	7	8.2	69	81.2
3	2	2.4	71	83.5
4	5	5.9	76	89.4
5	2	2.4	78	91.8
8	2	2.4	80	94.1
9	2	2.4	82	96.5
21	1	1.2	83	97.6
24	1	1.2	84	98.8
36	1	1.2	85	100.0

Table 9. Frequency Distribution of "Struck By" (STRUB) Accidents

STRUB	Frequency	Percent	Cumulative Freq.	Cumulative %
0	41	48.2	41	48.2
1	16	18.8	57	67.1
2	5	5.9	62	72.9
3	8	9.4	70	82.4
4	2	2.4	72	84.7
5	1	1.2	73	85.9
6	2	2.4	75	88.2
7	2	2.4	77	90.6
8	1	1.2	78	91.8
9	1	1.2	79	92.9
11	1	1.2	80	94.1
13	1	1.2	81	95.3
18	1	1.2	82	96.5
21	1	1.2	83	97.6
24	1	1.2	84	98.8
25	1	1.2	85	100.0

Table 10. Frequency Distribution of "Caught In" (COTIN) Accidents

COTIN	Frequency	Percent	Cumulative Freq.	Cumulative %
0	60	70.6	60	70.6
1	15	17.6	75	88.2
2	2	2.4	77	90.6
3	2	2.4	79	92.9
4	1	1.2	80	94.1
5	1	1.2	81	95.3
6	1	1.2	82	96.5
7	1	1.2	83	97.6
8	1	1.2	84	98.8
9	1	1.2	85	100.0

Table 11. Frequency Distribution of "Fall to the Same Level" (FALSAM) Accidents

FALSAM	Frequency	Percent	Cumulative Freq.	Cumulative %
0	56	65.9	56	65.9
1	13	15.3	69	81.2
2	4	4.7	73	85.9
3	6	7.1	79	92.9
8	1	1.2	80	94.1
9	1	1.2	81	95.3
12	1	1.2	82	96.5
16	1	1.2	83	97.6
18	1	1.2	84	98.8
20	1	1.2	85	100.0

Table 12. Frequency Distribution of "Fall to Different Level" (FALDIF) Accidents

FALDIF	Frequency	Percent	Cumulative Freq.	Cumulative %
0	55	64.7	55	64.7
1	16	18.8	71	83.5
2	6	7.1	77	90.6
3	3	3.5	80	94.1
4	1	1.2	81	95.3
8	3	3.5	84	98.8
9	1	1.2	85	100.0

Table 13. Frequency Distribution of "Overextension or Bodily Reaction" (OVEXT) Accidents

OVEXT	Frequency	Percent	Cumulative Freq.	Cumulative %
0	40	47.1	40	47
1	20	23.5	60	70.6
2	3	3.5	63	74.1
3	5	5.9	68	80.0
4	4	4.7	72	84.7
5	3	3.5	75	88.2
6	3	3.5	78	91.8
7	1	1.2	79	92.9
8	2	2.4	81	95.3
9	1	1.2	82	96.5
10	1	1.2	83	97.6
12	1	1.2	84	98.8
25	1	1.2	85	100.0

Table 14. Frequency Distribution of "Contact with Temperature or Pressure Extremes" (COTEMP) Accidents

COTEMP	Frequency	Percent	Cumulative Freq.	Cumulative %
0	71	83.5	71	83.5
1	9	10.6	80	94.1
2	2	2.4	82	96.5
4	1	1.2	83	97.6
5	1	1.2	84	98.8
6	1	1.2	85	100.0

Table 15. Frequency Distribution of Contact with Radiation, Caustics, & Toxic Substances" (COTOX) Accidents

COTOX	Frequency	Percent	Cumulative Freq.	Cumulative %
0	75	88.2	75	88.2
1	5	5.9	80	94.1
2	4	4.7	84	98.8
4	1	1.2	85	100.0

Table 16. Frequency Distribution of "Contact with Electric Current" (CONEL) Accidents

CONEL	Frequency	Percent	Cumulative Freq.	Cumulative %
0	83	97.6	83	97.6
1	1	1.2	84	98.8
3	1	1.2	85	100.0

Table 17. Frequency Distribution of "Stepped on Object" (STEPD) Accidents

STEPD	Frequency	Percent	Cumulative Freq.	Cumulative %
0	66	77.6	66	77.6
1	13	15.3	79	92.9
4	2	2.4	81	95.3
6	1	1.2	82	96.5
7	1	1.2	83	97.6
9	2	2.4	85	100.0

Table 18. Frequency Distribution of "Cut By" (CUT) Accidents

CUT	Frequency	Percent	Cumulative Freq.	Cumulative %
0	75	88.2	75	88.2
1	7	8.2	82	96.5
2	2	2.4	84	98.8
9	1	1.2	85	100.0

Table 19. Frequency Distribution of "Foreign Object in Eye" (FOREYE) Accidents.

FOREYE	Frequency	Percent	Cumulative Freq.	Cumulative %
0	42	49.4	42	49.4
1	24	28.2	66	77.6
2	8	9.4	74	87.1
3	1	1.2	75	88.2
4	2	2.4	77	90.6
5	1	1.2	78	91.8
6	1	1.2	79	92.9
7	1	1.2	80	94.1
8	3	3.5	83	97.6
13	1	1.2	84	98.8
14	1	1.2	85	100.0

number of stories of projects included in the data is one while the maximum is 18 stories; the minimum building area included is 2,000 square feet and the maximum is 937,000 square feet; the smallest contract amount included is $252,000 and the largest one is $98-million, and so on. It should be noted that the starting date of projects (STDAT) is a meaningless statistic in most of the analysis in this study, since it is merely a listing of the month and year when the projects included in the study started. Even though the starting date of projects appears to be insignificant in this case study conducted in Florida, it could become a very important statistic when conducting a similar study for other regions of the country where changes and seasons are more pronounced.

Table 21 presents the total number of data points observed, the mean, standard deviation and sum of all the variables included in the study. Some of the results of this analysis show statistics that can be misleading. A good example is the column labelled "Sum". While the sum of variables such as the experience and size of the contractor, project duration, area, contract amount and total number of accidents can be meaningful statistics, the sum of the starting dates of projects is meaningless.

Having examined the frequency distributions and simple statistics of the variables included in the data set, the data was further analyzed to investigate the relationship between the variables. Intuitively, some relationship is expected to

Table 20. Correlation Analysis: Minimum and Maximum values of Variables

Variable	Minimum	Maximum
CONEX (Experience of contractor)	8 yrs.	30 yrs.
CONSIZ (Size of contractor)	$14,000,000	$350,000,000
DUR (Contract duration)	6 mo.	48 mo.
STDAT (Starting date of contract)	1/86	12/88
PROSF (Building floor area)	2,000 SF	937,000 SF
PROSTO (number of stories)	1	18
PRAMT (contract amount)	$252,000	$98,800,000
TOTAC (Total number of accidents)	0	98

Table 21. Correlation Analysis - Simple Statistics

8 'VAR' Variables: CONEX CONSIZ DUR STDAT PROSF PROSTO PRAMT TOTAC

Variable	N	Mean	Std Dev	Sum
CONEX	85	24	6	2058
CONSIZ	85	148329412	115208650	1.2608E10
DUR	85	15	7	1235
PROSF	85	177059	213536	15050000
PROSTO	85	4	3	301
PRAMT	85	11631729	19972960	988697000
TOTAC	85	12	20	1078

exist between the variables included in the case study and the total number of accidents. The relationships were examined and the results are presented graphically in Figures 10 through 15 respectively. Figure 10 presents the relationship between the experience of contractor (in years) and the total number of accidents.

Figure 10 indicates that the more experienced contractors observed had more accidents than the less experienced ones. While this may be contrary to general expectations, it can be explained by the fact that there were more experienced contractors than less experienced ones in the data set. Secondly, it appears that the more experienced contractors performed more and larger contracts than their smaller counterparts, thus increasing their probability of experiencing more accidents.

Figure 11 presents the relationship between the size of contractor (in millions of dollars) and the number of accidents and shows that the smaller contractors observed experienced more accidents than their larger counterparts. This may be an indication that the larger contractors may be devoting more attention to safety than the smaller ones.

Figure 12 presents the relationship between the duration of the projects (in months) observed and the total number of accidents. This analysis indicates that projects between 12 and 24 months experienced more accidents than the ones over 24 months.

```
Plot of CONEX*TOTAC.  Legend: A = 1 obs, B = 2 obs, etc.
         |
CONEX    +
(yrs.)   |
    30   +  AQEDBAB   B A  A         A  A              A
         |
    28   +
         |
         |
    26   +
         |
         |
    24   +
         |
         |
    22   +    EFEAABAAA                  AA           A
         |
         |
    20   +  FA A   A          A  A          A      A
         |
         |
    18   +
         |
         |
    16   +
         |
         |
    14   +
         |
         |
    12   +
         |
         |
    10   +
         |
         |
     8   +   CBA A
         |
        +---------+---------+---------+---------+---------+--
             0        20        40        60        80       100

                                TOTAC
```

Figure 10. The Relationship between the Variable CONEX (Experience of Contractor) and TOTAC (Total Number of Accidents)

Even though the a more in-depth study of this relationship may be necessary, it may be speculated that contracts between 12 and 24 months may have put contractors in a position of meeting tight completion schedules, thereby increasing the probability of their experiencing more accidents. However, this relationship can also be explained by the fact that there were more contracts with a duration of 12 to 24 months in the data set than those over 24 months.

Figure 13 presents the relationship between the building floor area (measured in square feet) of the projects observed and the total number of accidents. This analysis indicates that the projects with smaller floor areas experienced more accidents than the ones with larger areas. This can be explained by the fact that there were more projects with small floor areas in the data set than there were large ones. As a result, some bias may exist towards small contracts.

Figure 14 presents the relationship between the number of stories in the projects observed and the total number of accidents. Figure 14 indicates that projects that were between one to four stories high experienced more accidents than those over four stories high. While this may be partially due to the fact that workers were more careful when working at higher elevations and the fact that most of the hi-rise projects were undertaken by large contractors with more sophisticated safety

Plot of CONSIZ*TOTAC. Legend: A = 1 obs, B = 2 obs, etc.

```
CONSIZ      |
($-million) |
        350 +  FA A    A           A  A          A     A
            |
            |
            |
            |
        300 +
            |
            |
            |
            |
        250 +
            |
            |
            |    EEEAABAAA                  AA          A
            |
        200 +
            |
            |
            |
            |
        150 +
            |
            |
            |
            |   CA  A      A
        100 +
            |
            |
            |
            |
         50 +  ANDDB B   B    A         A  A
            |
            |     A
            |   CBA A
            |
          0 +
            --+------+--------+--------+--------+------+
              0     20       40       60       80    100

                                     TOTAC
```

Figure 11. The Relationship between the Variable CONSIZ (the Size of Contractor) and the Total Number of Accidents

```
Plot of DUR*TOTAC.  Legend: A = 1 obs, B = 2 obs, etc.
DUR (months)
 48 +   A
 47 +
 46 +
 45 +
 44 +
 43 +
 42 +
 41 +
 40 +
 39 +
 38 +
 37 +
 36 +     A
 35 +
 34 +
 33 +
 32 +
 31 +
 30 +
 29 +
 28 +                              A
 27 +
 26 +
 25 +
 24 +   AAA      A         A                    A A
 23 +
 22 +      A A                                    A
 21 +                           A
 20 +         A
 19 +     A
 18 +  AC        A    A                  A
 17 +  AA
 16 +   A B        A                A
 15 +   A A  A               A
 14 +   AA BA  B
 13 +   D        A
 12 +  CDBAA
 11 +    A                           A
 10 +   BB  A
  9 +    A A  B A
  8 +  BABC A
  7 +    AAA
  6 +   AAAA
    |--+------+---------+---------+---------+---------+
       0     20        40        60        80       100
                               TOTAC
```

Figure 12. Relationship between the Variable DUR (Duration of Projects) and Total Number of Accidents

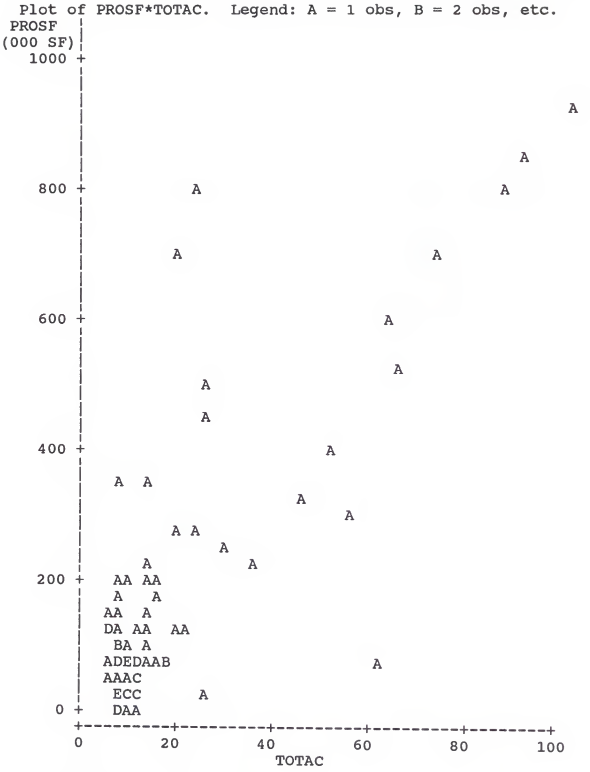

Figure 13. The Relationship between the Variable PROSF (Square Feet of Building Area) and the Total Number of Accidents

programs, the fact cannot be overlooked that there were more projects in the 1 to 4 stories range than there were hi-rise projects in the data set.

Figure 15 presents the relationship between the amount of contract (in millions of dollars) and the total number of accidents, and indicates that the smaller contracts observed experienced more accidents than the larger size contracts. One reason could be that the smaller contracts were undertaken by small contractors with less sophisticated safety programs. However, it should be noted some bias towards the small size contracts exists because there were more small contracts than large ones in the data set used for this case study.

The next type of correlation analysis performed was to determine the Pearson correlation coefficient (r). The Pearson correlation coefficient, a number that ranges from -1 to +1, is a common statistic that shows the strength of a relationship that exists between two continuous variables.

The correlation coefficient was calculated using SAS procedures. Although the derivation of the correlation coefficient is beyond the scope of this thesis, it can be obtained as follows

$$r=\frac{\text{the mean product of the deviat. from the mean of each variable}}{\text{the std. deviation of the 1st X the std. deviation of the 2nd}}$$

Plot of PROSTO*TOTAC. Legend: A = 1 obs, B = 2 obs, etc.

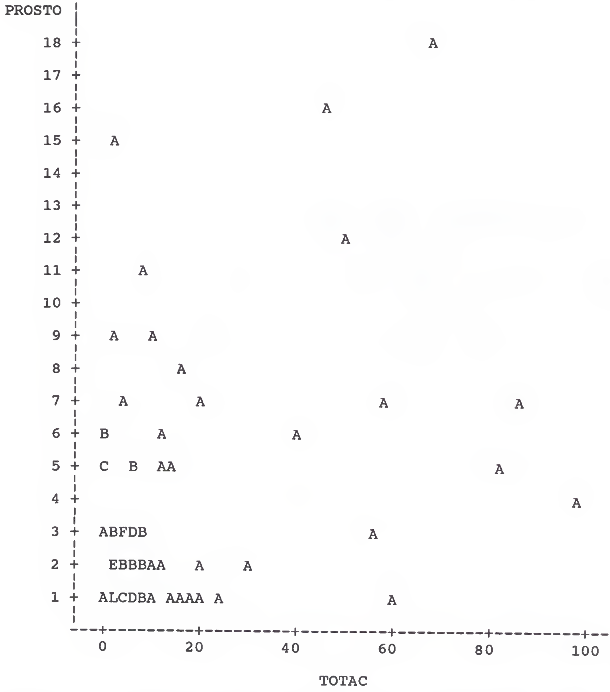

Figure. 14 The Relationship between Variable PROSTO (Number of Stories) and the Total Number of Accidents

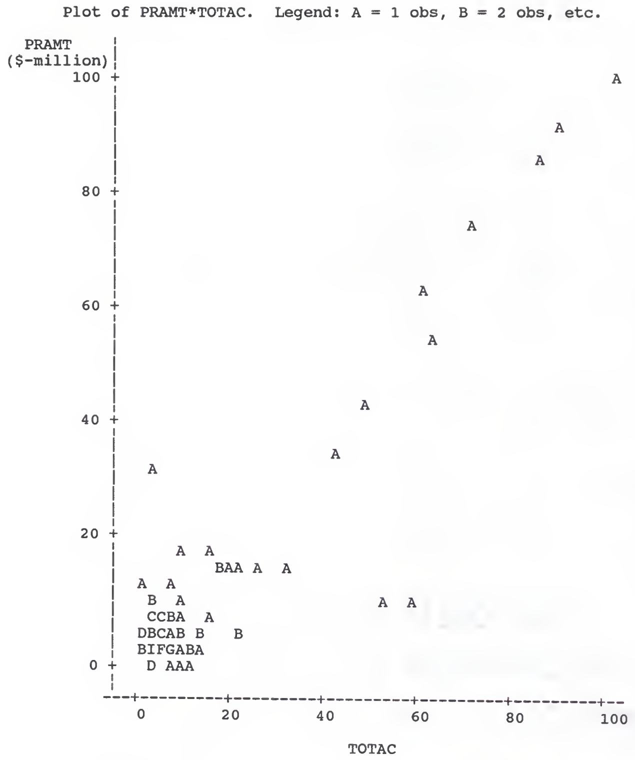

Figure 15. The Relationship between the Variable PRAMT (Amount of Contract) and the Total Number of Accidents

For example, If x is the deviation from the mean of one of the first variables, y is the deviation from the mean of the corresponding second variable and n is the number of observations, then

$$r = \frac{\underline{\text{Sum of the terms like } xy}}{\sqrt{\dfrac{\text{Sum of terms like } x^2}{n}} \times \sqrt{\dfrac{\text{Sum of the terms like } y^2}{n}}}$$

$$= \frac{\text{Sum of the terms like } xy}{\sqrt{\text{Sum of the terms like } x^2} \times \sqrt{\text{Sum of the terms like } y^2}}$$

or given n pairs of observations (x_i, y_i), r can be computed as

$$r = \frac{\Sigma_{xy}}{\sqrt{\Sigma_{xx}\Sigma_{yy}}}$$

Tables 22 and 23 present the Pearson Correlation Coefficients for the variables included in the data set used in the case history to demonstrate the model approach.

A positive correlation coefficient usually means that as the values of one variable increases, the values of the other variable will also tend to increase. Conversely, a negative correlation coefficient means that as the values of

one variable goes up, the values of the other variable will tend to go down. It is important to note that a negative correlation shows an equally strong relationship between variables as a positive correlation, even though the relationship is inverse. In other words, a correlation of -0.20 is just as strong as one of +0.20. For example in Table 23, the correlation coefficient between the variables TOTAC (the total number of accidents) and PRAMT (contract amount) is 0.90. A small or zero correlation coefficient usually means that the two variables involved are unrelated. It is also important to remember that a correlation coefficient is an indicator of the strength of the relationship between two variables, and does not necessarily imply causality.

In addition to the correlation coefficients in Tables 22 and 23, SAS also provides the probability associated with each coefficient. For example in Table 23, besides giving the correlation coefficient between TOTAC and PRAMT as 0.90, it also shows a probability of 0.0001. The latter number gives the probability of obtaining a sample correlation coefficient as large or larger than the 0.90 obtained (by chance alone) if the two variables had zero correlation.

Phase IV: Data Evaluation/Model Development

After it was determined that most of the correlation coefficients of the variables used in this case study were significantly different from zero, the next step was to

Table 22. Correlation Analysis (Pearson Correlation Coefficient)

CORRELATION ANALYSIS

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 85

	CONEX	CONSIZ	DUR	STDAT
CONEX	1.00000 0.0	-0.30138 0.0051	0.31071 0.0038	-0.02879 0.7937
CONSIZ	-0.30138 0.0051	1.00000 0.0	-0.18923 0.0828	0.04457 0.6854
DUR	0.31071 0.0038	-0.18923 0.0828	1.00000 0.0	0.16511 0.1310
STDAT	-0.02879 0.7937	0.04457 0.6854	0.16511 0.1310	1.00000 0.0
PROSF	-0.00938 0.9321	0.33861 0.0015	0.17140 0.1168	0.00828 0.9401
PROSTO	-0.03161 0.7739	0.40177 0.0001	0.14554 0.1838	0.07647 0.4867
PRAMT	-0.02668 0.8085	0.32657 0.0023	0.28941 0.0072	-0.05609 0.6101
TOTAC	-0.00646 0.9532	0.22331 0.0399	0.31711 0.0031	0.00675 0.9511

interpret the importance of the correlation during the model development process. As Cody and Smith (1987) asserted:

> One of the best ways of interpreting a correlation coefficient (r) is to look at the square of the coefficient (R-squared). (p. 73)

R-squared can be defined as the proportion of variance in one variable that can be explained by the variation in the other variable. For instance in Table 23, the contract amount (PRAMT)/TOTAC correlation was 0.90400. Thus R-squared is 0.81. Based on this, it can be interpreted that 81% of the total number of accidents can be explained by the variation in contract amount or vice versa. On the other hand, it can be said that 19% (100 - 81) of the variance in the total number of accidents may be due to factors other than contract amount.

Using this as background, R-squared was determined for the independent variables in the case study in order to select the best regressors to use in the proposed model. The criteria used was to select the factor(s) with: a). a C(p) closest to the number of variables in the model; and b). the factor(s) with the highest R-squared values.

Table 24 presents regression models for the total number of accidents, based on one independent variable. Using the criteria outlined above, the best factor in Table 24 was PRAMT (contract amount).

Table 23. Correlation Analysis (Pearson Correlation Coefficient)

CORRELATION ANALYSIS

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 85

	PROSF	PROSTO	PRAMT	TOTAC
CONEX	-0.00938 0.9321	-0.03161 0.7739	-0.02668 0.8085	-0.00646 0.9532
CONSIZ	0.33861 0.0015	0.40177 0.0001	0.32657 0.0023	0.22331 0.0399
DUR	0.17140 0.1168	0.14554 0.1838	0.28941 0.0072	0.31711 0.0031
STDAT	0.00828 0.9401	0.07647 0.4867	-0.05609 0.6101	0.00675 0.9511
PROSF	1.00000 0.0	0.35855 0.0008	0.83477 0.0001	0.79342 0.0001
PROSTO	0.35855 0.0008	1.00000 0.0	0.36619 0.0006	0.37699 0.0004
PRAMT	0.83477 0.0001	0.36619 0.0006	1.00000 0.0	0.90400 0.0001
TOTAC	0.79342 0.0001	0.37699 0.0004	0.90400 0.0001	1.00000 0.0

Table 25 presents regression models for the total number of accidents using two factors. From this table, it appears that the two best factors with the highest R-squared values and the c(p) values closest to 2 are CONSIZ and PRAMT (the size of a contractor and the amount of contract, respectively). It was also noted that the R-squared value went from 81% (with one variable, PRAMT) to 82% (with the addition of the second variable. This is an indication that the contract amount of a project is much more significant than the size of a contractor in the illustrative accident prediction model being developed.

Table 26 indicates that the best model with three independent variables is the one with CONSIZ, PROSF and PRAMT (size of a contractor, square foot area of the building and the project contract amount respectively).

In Table 27, it was observed that the best model with four independent variables is the one that has CONSIZ, PROSF, PROSTO and PRAMT (size of a contractor, square footage of a project, number of stories and project contract amount). It was observed that the increase in the value of R-squared with four variables in Table 27 is very minimal in comparison to the value of R-squared with three variables in Table 26. This can be interpreted to mean that the fourth variable may not be too significant. Note that all models that included STDAT (the starting date of a project) were disregarded based on previous explanation that it was a meaningless statistic in the case history.

Table 24. Regression Models with One Independent Variable

Number in Model	R-square	C(p)	Variables in Model
1	0.81722351	6.03298	PRAMT
1	0.62950850	95.41755	PROSF
1	0.14212210	327.49713	PROSTO
1	0.10055602	347.28972	DUR
1	0.04986935	371.42528	CONSIZ
1	0.00004554	395.14996	STDAT
1	0.00004178	395.15175	CONEX

Table 25. Regression Models with Two Independent Variables.

Number in Model	R-square	C(p)	Variables in Model
2	0.82301136	5.27697	CONSIZ PRAMT
2	0.82218475	5.67058	PROSF PRAMT
2	0.82058228	6.43363	DUR PRAMT
2	0.82053524	6.45603	STDAT PRAMT
2	0.81966266	6.87153	PROSTO PRAMT
2	0.81753548	7.88443	CONEX PRAMT
2	0.66330329	81.32543	DUR PROSF
2	0.63932902	92.74129	PROSF PROSTO
2	0.63183051	96.31187	CONSIZ PROSF
2	0.62950947	97.41709	CONEX PROSF
2	0.62950854	97.41753	STDAT PROSF
2	0.21237859	296.04298	DUR PROSTO
2	0.18380673	309.64809	CONSIZ DUR
2	0.14827849	326.56563	CONSIZ PROSTO
2	0.14261242	329.26365	STDAT PROSTO
2	0.14215188	329.48295	CONEX PROSTO
2	0.11275683	343.48004	CONEX DUR
2	0.10269464	348.27137	DUR STDAT
2	0.05394053	371.48669	CONEX CONSIZ
2	0.04987965	373.42037	CONSIZ STDAT
2	0.00008487	397.13123	CONEX STDAT

Other four-variable models were not considered because either their C(p) value or R-squared value did not meet the model selection criteria previously established. For example, after the fourth model, the C(p) values of the remaining models begin to increase, while the R-squared values begin to drop from 0.83 to 0.14 in the last model in Table 27. Table 28 presents models with five independent variables. It was observed that the best model was the one that included CONSIZ, DUR, PROSF, PROSTO and PRAMT (size of a contractor, duration of a contract, square foot area of a building, number of stories in a project and project contract amount respectively). It was also observed that the change in the R-squared value from four to five independent variables was very small. Again this can be an indication that the fifth variable is not too significant and may not be worth including in the final model.

In Table 29, the best model with six independent variables was observed as the with the size of a contractor, duration of a project, starting date of a project, square foot area of a building, number of stories in a project and the project contract amount. However, the increase in the value of R-squared from the five-variable model to the six-variable model appears to be insignificant.

Table 30 indicates that there was only one model with seven variables. This model included all the independent variables selected for this research. However, with a C(p) value of 8, and a rather insignificant increase of 0.00053559 in

Table 26. Regression Models with Three Independent Variables

Number in Model	R-square	C(p)	Variables in Model
3	0.82952959	4.17317	CONSIZ PROSF PRAMT
3	0.82908216	4.38623	CONSIZ PROSTO PRAMT
3	0.82694985	5.40157	CONSIZ STDAT PRAMT
3	0.82680073	5.47258	DUR PROSF PRAMT
3	0.82475964	6.44449	STDAT PROSF PRAMT
3	0.82430066	6.66304	CONSIZ DUR PRAMT
3	0.82397787	6.81675	PROSF PROSTO PRAMT
3	0.82304990	7.25862	CONEX CONSIZ PRAMT
3	0.82283017	7.36325	DUR STDAT PRAMT
3	0.82277812	7.38803	DUR PROSTO PRAMT
3	0.82244132	7.54841	CONEX PROSF PRAMT
3	0.82243773	7.55012	STDAT PROSTO PRAMT
3	0.82091228	8.27649	CONEX STDAT PRAMT
3	0.82058525	8.43222	CONEX DUR PRAMT
3	0.82001714	8.70274	CONEX PROSTO PRAMT
3	0.67013213	80.07373	DUR PROSF PROSTO
3	0.66695311	81.58748	CONEX DUR PROSF
3	0.66425140	82.87396	DUR STDAT PROSF
3	0.66330406	83.32506	CONSIZ DUR PROSF
3	0.64642259	91.36353	CONSIZ PROSF PROSTO
3	0.63938745	94.71347	STDAT PROSF PROSTO
3	0.63934488	94.73374	CONEX PROSF PROSTO
3	0.63205755	98.20376	CONEX CONSIZ PROSF
3	0.63183591	98.30930	CONSIZ STDAT PROSF
3	0.62950951	99.41707	CONEX STDAT PROSF
3	0.23699911	286.31939	CONSIZ DUR PROSTO
3	0.21933647	294.72984	CONEX DUR PROSTO
3	0.21651401	296.07381	DUR STDAT PROSTO
3	0.18857399	309.37806	CONSIZ DUR STDAT
3	0.18515553	311.00583	CONEX CONSIZ DUR
3	0.14929156	328.08324	CONEX CONSIZ PROSTO
3	0.14882308	328.30632	CONSIZ STDAT PROSTO
3	0.14263617	331.25235	CONEX STDAT PROSTO
3	0.11588005	343.99285	CONEX DUR STDAT
3	0.05394529	373.48443	CONEX CONSIZ STDAT

Table 27. Regression Models with Four Independent Variables

Number in Model	R-square	C(p)	Variables in Model
4	0.83481557	3.65614	CONSIZ PROSF PROSTO PRAMT
4	0.83261093	4.70593	CONSIZ STDAT PROSF PRAMT
4	0.83223262	4.88607	CONSIZ STDAT PROSTO PRAMT
4	0.83147716	5.24580	CONSIZ DUR PROSF PRAMT
4	0.82966418	6.10909	CONEX CONSIZ PROSF PRAMT
4	0.82964153	6.11987	CONSIZ DUR PROSTO PRAMT
4	0.82924653	6.30796	CONEX CONSIZ PROSTO PRAMT
4	0.82827556	6.77031	DUR PROSF PROSTO PRAMT
4	0.82821110	6.80100	DUR STDAT PROSF PRAMT
4	0.82745686	7.16015	CONSIZ DUR STDAT PRAMT
4	0.82698084	7.38682	CONEX CONSIZ STDAT PRAMT
4	0.82685633	7.44611	CONEX DUR PROSF PRAMT
4	0.82618037	7.76798	STDAT PROSF PROSTO PRAMT
4	0.82507274	8.29540	CONEX STDAT PROSF PRAMT
4	0.82462995	8.50625	DUR STDAT PROSTO PRAMT
4	0.82456113	8.53901	CONEX CONSIZ DUR PRAMT
4	0.82427118	8.67708	CONEX PROSF PROSTO PRAMT
4	0.82285036	9.35364	CONEX STDAT PROSTO PRAMT
4	0.82283966	9.35873	CONEX DUR STDAT PRAMT
4	0.82277815	9.38802	CONEX DUR PROSTO PRAMT
4	0.67319451	80.61551	CONEX DUR PROSF PROSTO
4	0.67144365	81.44922	DUR STDAT PROSF PROSTO
4	0.67107712	81.62375	CONSIZ DUR PROSF PROSTO
4	0.66826255	82.96397	CONEX DUR STDAT PROSF
4	0.66717725	83.48075	CONEX CONSIZ DUR PROSF
4	0.66426562	84.86719	CONSIZ DUR STDAT PROSF
4	0.64703136	93.07366	CONEX CONSIZ PROSF PROSTO
4	0.64645773	93.34680	CONSIZ STDAT PROSF PROSTO
4	0.63940175	96.70666	CONEX STDAT PROSF PROSTO
4	0.63206192	100.20168	CONEX CONSIZ STDAT PROSF
4	0.24247486	285.71199	CONSIZ DUR STDAT PROSTO
4	0.23907726	287.32983	CONEX CONSIZ DUR PROSTO
4	0.22442535	294.30666	CONEX DUR STDAT PROSTO
4	0.19029531	310.55841	CONEX CONSIZ DUR STDAT
4	0.14980301	329.83970	CONEX CONSIZ STDAT PROSTO

the R-square value from six to seven independent variables, it is obvious that the seven-variable model would not be a good one.

The next step in the model development phase will be to conduct other statistical analysis to confirm the results obtained here before selecting the trial models.

Phase V: Accident Prediction Models

Based on the preceding analyses, it appeared that the most promising model would be one with three or four independent variables. However, before a final conclusion was drawn on the number variables to include in the model, two additional analyses were conducted using the SAS "Forward" and "Maxr" regression techniques. In the forward regression technique, each factor (regressor) was introduced one at a time, starting with the best regressor and then adding the next best and so forth. The results are presented in Tables 31 through 36. Tables 33 and 34 indicate that the two models with the most acceptable C(p) and R-squared values are the three-variable and four-variable models.

The Maxr regression procedure provides the best one-variable model with the best R^2, then finds the best two-variable model with the best R^2 until such time that no further improvement in R^2 can be found. The results of the Maxr regression procedure presented in Tables 37 through 43 indicate that the three-variable model (Table 39) and the

Table 28. Regression Models with Five Independent Variables.

Number in Model	R-square	C(p)	Variables in Model
5	0.83728566	4.47996	CONSIZ STDAT PROSF PROSTO PRAMT
5	0.83585910	5.15924	CONSIZ DUR PROSF PROSTO PRAMT
5	0.83512144	5.51050	CONEX CONSIZ PROSF PROSTO PRAMT
5	0.83363790	6.21692	CONSIZ DUR STDAT PROSF PRAMT
5	0.83272514	6.65155	CONEX CONSIZ STDAT PROSF PRAMT
5	0.83237755	6.81706	CONSIZ DUR STDAT PROSTO PRAMT
5	0.83237247	6.81948	CONEX CONSIZ STDAT PROSTO PRAMT
5	0.83207240	6.96236	CONEX CONSIZ DUR PROSF PRAMT
5	0.83001767	7.94077	CONEX CONSIZ DUR PROSTO PRAMT
5	0.82946030	8.20617	DUR STDAT PROSF PROSTO PRAMT
5	0.82830671	8.75548	CONEX DUR PROSF PROSTO PRAMT
5	0.82822191	8.79585	CONEX DUR STDAT PROSF PRAMT
5	0.82760319	9.09047	CONEX CONSIZ DUR STDAT PRAMT
5	0.82652514	9.60381	CONEX STDAT PROSF PROSTO PRAMT
5	0.82464931	10.49703	CONEX DUR STDAT PROSTO PRAMT
5	0.67530571	81.61021	CONEX CONSIZ DUR PROSF PROSTO
5	0.67487281	81.81635	CONEX DUR STDAT PROSF PROSTO
5	0.67223285	83.07342	CONSIZ DUR STDAT PROSF PROSTO
5	0.66841458	84.89158	CONEX CONSIZ DUR STDAT PROSF
5	0.64707291	95.05387	CONEX CONSIZ STDAT PROSF PROSTO
5	0.24505287	286.48442	CONEX CONSIZ DUR STDAT PROSTO

Table 29. Regression Models with Six Variables.

Number in Model	R-square	C(p)	Variables in Model
6	0.83775802	6.25503	CONSIZ DUR STDAT PROSF PROSTO PRAMT
6	0.83755260	6.35285	CONEX CONSIZ STDAT PROSF PROSTO PRAMT
6	0.83657903	6.81643	CONEX CONSIZ DUR PROSF PROSTO PRAMT
6	0.83405922	8.01630	CONEX CONSIZ DUR STDAT PROSF PRAMT
6	0.83261811	8.70251	CONEX CONSIZ DUR STDAT PROSTO PRAMT
6	0.82946383	10.20449	CONEX DUR STDAT PROSF PROSTO PRAMT
6	0.67678251	82.90700	CONEX CONSIZ DUR STDAT PROSF PROSTO

Table 30. Regression Model with Seven Independent Variables

Number in Model	R-square	C(p)	Variables in Model
7	0.83829361	8.00000	CONEX CONSIZ DUR STDAT PROSF PROSTO PRAMT

four-variable model (Table 40) are the best out of all the models developed. These results supported and confirmed the previous inference that the best model would be either a three-variable or four-variable one. These two models were therefore selected for further examination. The results of this examination and a final accident prediction model are presented in detail in the next chapter.

Table 31. Model for Total Number of Accidents with One Variable (Contract Amount)

Forward Selection Procedure for Dependent Variable TOTAC Step 1

Step 1 Variable PRAMT Entered R-square = 0.81722351 C(p) = 6.03298412

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	29167.05302533	29167.05302533	371.11	0.0001
Error	83	6523.37050408	78.59482535		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	1.83038502	1.11444171	212.01380618	2.70	0.1043
PRAMT	0.00000093	0.00000005	29167.05302533	371.11	0.0001

Bounds on condition number: 1, 1

Table 32. Model for Total Number of Accidents with Two Variables (Contract Amount and Number of Stories).

Step 2 Variable CONSIZ Entered R-square = 0.82301136 C(p) = 5.27697214

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	29373.62398741	14686.81199371	190.65	0.0001
Error	82	6316.79954200	77.03414076		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	3.65096049	1.56631878	418.54021863	5.43	0.0222
CONSIZ	-0.00000001	0.00000001	206.57096208	2.68	0.1053
PRAMT	0.00000096	0.00000005	27593.76581328	358.20	0.0001

Bounds on condition number: 1.11938, 4.47752

Table 33. Model for Total Number of Accidents with Three Variables (Contract Amount, Number of Stories and Duration).

Step 3 Variable PROSF Entered R-square = 0.82952959 C(p) = 4.17317388

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	29606.26252369	9868.75417456	131.39	0.0001
Error	81	6084.16100572	75.11309884		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	2.85272366	1.61180144	235.29462731	3.13	0.0805
CONSIZ	-0.00000002	0.00000001	262.14047302	3.49	0.0654
PROSF	0.00001427	0.00000811	232.63853627	3.10	0.0822
PRAMT	0.00000084	0.00000009	7055.96398144	93.94	0.0001

Bounds on condition number: 3.352469, 23.43771

Table 34. Model for Total Number of Accidents with Four Variables (Size of Contractor, Number of Stories, Square Foot Area of Building and Contract Amount)

Step 4 Variable PROSTO Entered R-square = 0.83481557 C(p) = 3.65614102

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	4	29794.92131860	7448.73032965	101.08	0.0001
Error	80	5895.50221081	73.69377764		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	2.12218303	1.66050713	120.36909830	1.63	0.2049
CONSIZ	-0.00000002	0.00000001	386.80215458	5.25	0.0246
PROSF	0.00001341	0.00000805	204.62776680	2.78	0.0996
PROSTO	0.48926558	0.30578878	188.65879491	2.56	0.1135
PRAMT	0.00000082	0.00000009	6723.82512855	91.24	0.0001

Bounds on condition number: 3.367376, 37.13299

Table 35. Model for Total Number of Accidents with Five Variables (Size of Contractor, Project Starting Date, Square Foot Area of Building, Number of Stories and Contract Amount)

Step 5 Variable STDAT Entered R-square = 0.83728566 C(p) = 4.47995526

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	5	29883.07979744	5976.61595949	81.30	0.0001
Error	79	5807.34373198	73.51068015		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	0.06899756	2.50311286	0.05585436	0.00	0.9781
CONSIZ	-0.00000002	0.00000001	396.35241312	5.39	0.0228
STDAT	0.00299700	0.00273672	88.15847884	1.20	0.2768
PROSF	0.00001264	0.00000807	180.34502522	2.45	0.1213
PROSTO	0.46167179	0.30644634	166.84309565	2.27	0.1359
PRAMT	0.00000083	0.00000009	6810.72946459	92.65	0.0001

Bounds on condition number: 3.417806, 51.9874

No other variable met the 0.5000 significance level for entry into the model.

Table 36. Summary of Forward Regression Procedure

Step	Variable Entered	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	PRAMT	1	0.8172	0.8172	6.0330	371.1065	0.0001
2	CONSIZ	2	0.0058	0.8230	5.2770	2.6816	0.1053
3	PROSF	3	0.0065	0.8295	4.1732	3.0972	0.0822
4	PROSTO	4	0.0053	0.8348	3.6561	2.5600	0.1135
5	STDAT	5	0.0025	0.8373	4.4800	1.1993	0.2768

Table 37. Best 1-variable Model

Maximum R-square Improvement for Dependent Variable TOTAC

Step 1 Variable PRAMT Entered R-square = 0.81722351 C(p) = 6.03298412

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	29167.05302533	29167.05302533	371.11	0.0001
Error	83	6523.37050408	78.59482535		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	1.83038502	1.11444171	212.01380618	2.70	0.1043
PRAMT	0.00000093	0.00000005	29167.05302533	371.11	0.0001

Bounds on condition number: 1, 1

The above model is the best 1-variable model found.

Table 38. The Best 2-variable Model

Step 2 Variable CONSIZ Entered R-square = 0.82301136 C(p) = 5.27697214

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	29373.62398741	14686.81199371	190.65	0.0001
Error	82	6316.79954200	77.03414076		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	3.65096049	1.56631878	418.54021863	5.43	0.0222
CONSIZ	-0.00000001	0.00000001	206.57096208	2.68	0.1053
PRAMT	0.00000096	0.00000005	27593.76581328	358.20	0.0001

Bounds on condition number 1.11938 4.47752

The above model is the best 2-variable model found.

Table 39. The Best 3-Variable Model

Step 3 Variable PROSF Entered R-square = 0.82952959 C(p) = 4.17317388

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	29606.26252369	9868.75417456	131.39	0.0001
Error	81	6084.16100572	75.11309884		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	2.85272366	1.61180144	235.29462731	3.13	0.0805
CONSIZ	-0.00000002	0.00000001	262.14047302	3.49	0.0654
PROSF	0.00001427	0.00000811	232.63853627	3.10	0.0822
PRAMT	0.00000084	0.00000009	7055.96398144	93.94	0.0001

Bounds on condition number: 3.352469, 23.43771

The above model is the best 3-variable model found.

Table 40. The Best 4-Variable Model

Step 4 Variable PROSTO Entered R-square = 0.83481557 C(p) = 3.65614102

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	4	29794.92131860	7448.73032965	101.08	0.0001
Error	80	5895.50221081	73.69377764		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	2.12218303	1.66050713	120.36909830	1.63	0.2049
CONSIZ	-0.00000002	0.00000001	386.80215458	5.25	0.0246
PROSF	0.00001341	0.00000805	204.62776680	2.78	0.0996
PROSTO	0.48926558	0.30578878	188.65879491	2.56	0.1135
PRAMT	0.00000082	0.00000009	6723.82512855	91.24	0.0001

Bounds on condition number: 3.367376, 37.13299

The above model is the best 4-variable model found.

Table 41. The Best 5-Variable Model

Step 5 Variable STDAT Entered R-square = 0.83728566 C(p) = 4.47995526

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	5	29883.07979744	5976.61595949	81.30	0.0001
Error	79	5807.34373198	73.51068015		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	0.06899756	2.50311286	0.05585436	0.00	0.9781
CONSIZ	-0.00000002	0.00000001	396.35241312	5.39	0.0228
STDAT	0.00299700	0.00273672	88.15847884	1.20	0.2768
PROSF	0.00001264	0.00000807	180.34502522	2.45	0.1213
PROSTO	0.46167179	0.30644634	166.84309565	2.27	0.1359
PRAMT	0.00000083	0.00000009	6810.72946459	92.65	0.0001

Bounds on condition number: 3.417806, 51.9874

The above model is the best 5-variable model found.

Table 42. The Best 6-variable Model

Step 6 Variable DUR Entered R-square = 0.83775802 C(p) = 6.25502979

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	6	29899.93860303	4983.32310051	67.13	0.0001
Error	78	5790.48492638	74.23698624		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
		SAS			8
INTERCEP	-0.89170525	3.22360786	5.68039541	0.08	0.7828
CONSIZ	-0.00000002	0.00000001	296.14912463	3.99	0.0493
DUR	0.07503247	0.15745121	16.85880560	0.23	0.6350
STDAT	0.00269612	0.00282176	67.77332472	0.91	0.3423
PROSF	0.00001316	0.00000818	192.03147819	2.59	0.1118
PROSTO	0.43869934	0.31170669	147.04898837	1.98	0.1633
PRAMT	0.00000082	0.00000009	5907.66351024	79.58	0.0001

Bounds on condition number: 3.808772, 74.62318

The above model is the best 6-variable model found.

Table 43. The Best 7-variable Model

Step 7 Variable CONEX Entered R-square = 0.83829361 C(p) = 8.00000000

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	7	29919.05381388	4274.15054484	57.02	0.0001
Error	77	5771.36971553	74.95285345		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	0.96954604	4.90668790	2.92649760	0.04	0.8439
CONEX	-0.08122997	0.16084991	19.11521084	0.26	0.6150
CONSIZ	-0.00000002	0.00000001	315.13849734	4.20	0.0437
DUR	0.09767961	0.16444163	26.44675720	0.35	0.5542
STDAT	0.00257158	0.00284603	61.19379377	0.82	0.3690
PROSF	0.00001359	0.00000827	202.56083854	2.70	0.1043
PROSTO	0.44510570	0.31346278	151.12715734	2.02	0.1597
PRAMT	0.00000081	0.00000009	5764.39928930	76.91	0.0001

Bounds on condition number: 3.854778, 97.46916

The above model is the best 7-variable model found.

No further improvement in R-square is possible.

CHAPTER 6

RESULTS AND DISCUSSION

Introduction

How can one save lives? This is an important question facing all engineers in general and construction engineers in particular. Within the context of construction engineering and building construction sites where the number of accidents have been comparatively astronomical, the equivalent question is "How could an engineer make building construction sites safer during the physical construction process?". This study was aimed at developing a systematic approach that can enable an engineer to derive models for predicting the number of accidents to be expected on construction project sites, based on the notion that the number of accidents on building construction sites can be reduced if they can be predicted.

The objective of the study was accomplished by developing and describing a methodology for data collection, establishment of an appropriate database and the development of accident prediction models. The approach developed was then illustrated with a case study using accident data from 85 building construction projects and 10788 accident observations

in Florida. This chapter is a presentation of the findings from the analyses of the data used in the case study.

Results

Seven models were developed from the database created as part of the case study using regression analysis and with the aid of SAS software. A regression analysis of all possible models was performed and the Cp and R^2 statistics were computed for each model. The results are summarized in Table 29. Two trial models were then selected using Mallow's Cp theory as the major criteria. Mallow's theory states that the best fitted model occurs when the Cp value approaches or is approximately equal to the number of variables (P) in a model. Based on this theory, the two models selected were the ones with the highest R^2 of all the models whose Cp statistics were approximately equal to the number of parameters in those models.

As shown in Table 44, the two most promising models were model number 3 (with three variables, a Cp value of 4.17317 and a R^2 value of 0.82952959) and model number 4 (with four variables a Cp value of 3.65614 and a R^2 value of 0.83481557). However, further examination of these two models shows that the change in the R^2 value between model number 3 and 4 was an insignificant value of 0.0528598.

Table 44. Listing of Cp and R^2 Values for Preliminary Total Number of Accident Prediction Models

Model Number	Number of Parameters P	Mallow's statistic Cp	Coefficient of Determination R^2
1	1	6.03298	0.81722351
2	2	5.27697	0.82301136
3	3	4.17317	0.82952959
4	4	3.65614	0.83481557
5	5	5.15924	0.83585910
6	6	6.25503	0.83775802
7	7	8.00000	0.83829361

Based on these results and Cody and Smith's (1987) theory that models with fewer number of variables are more precise, model number 3 was chosen. This selection was further verified by using the SAS stepwise regression procedure. The stepwise technique is very similar to the forward procedure used previously except that all the variables are checked again to see if they still remain significant each time a new variable is introduced into the model. Again, the results of the stepwise regression analysis, presented in Tables 45 through 49 confirmed that model number 3 (Table 47) was the best. Using the model formulated in chapter 3 of this study, the base model was expressed as

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \epsilon$$

where

Y = estimated number of accidents per project

β_0 = estimate of intercept (obtained by regression analysis)

β_1 = estimate of slope for the independent variable CONSIZ (obtained by regression analysis)

β_2 = estimate of slope for the independent variable PROSF (obtained by regression analysis)

β_3 = estimate of slope for the independent variable PRAMT (obtained by regression analysis)

x_1 = size of contractor involved (given)

x_2 = building area of project for which the number of accidents to be expected is being estimated (given)

x_3 = contract amount of project (given)

ϵ = error term (= 0)

By substitution from Table 47, the base model for estimating the number of accidents per project can be expressed as

$$\text{ENAPPRO} = 2.8527 + [-(0.00000002)(X_1)] + [(0.00001427)(X_2)] + [(0.00000084)(X_3)] + 0$$

where

ENAPPRO = Estimated number of accidents per project

2.85272366 = intercept (estimated by regression)

0.00000002 = slope of CONSIZ (estimated by regression)

0.00001427 = slope of PROSF (estimated by regression)

0.00000084 = slope of PRAMT (estimated by regression)

0 = error term

As an example showing how the model can be used in predicting accidents, suppose a contractor whose average annual volume for the past five years is $220,000,000 has a been awarded a contract for $13,919,000 to construct a 500,000 square foot office building in Tampa Florida, the number of accidents to be expected on that project ENAPPRO) can be estimated as follows, using the model developed:

$$\text{ENNAPRO} = 2.85 + [-(0.00000002)(220{,}000{,}000)] + (0.00001427)(500{,}000) + (0.00000084)(13{,}919{,}000)$$
$$= 3 - 4 + 7 + 12 = 18 \text{ accidents}$$

Rounding the intercept (β_0) off from 2.85 to 3, it is estimated that 18 accidents are expected on the above project.

Table 45. Prediction Model with 1 Variable

PREDICTION MODEL FOR ESTIMATED TOTAL NUMBER OF ACCIDENTS

Stepwise Procedure for Dependent Variable TOTAC

Step 1 Variable PRAMT Entered R-square = 0.81722351 C(p) = 6.23829556

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	29167.05302533	29167.05302533	371.11	0.0001
Error	83	6523.37050408	78.59482535		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	1.83038502	1.11444171	212.01380618	2.70	0.1043
PRAMT	0.00000093	0.00000005	29167.05302533	371.11	0.0001

Bounds on condition number: 1, 1

Table 46. Prediction Model with 2 Variables

Step 2 Variable CONSIZ Entered R-square = 0.82301136 C(p) = 5.47578213

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	29373.62398741	14686.81199371	190.65	0.0001
Error	82	6316.79954200	77.03414076		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	3.65096049	1.56631878	418.54021863	5.43	0.0222
CONSIZ	-0.00000001	0.00000001	206.57096208	2.68	0.1053
PRAMT	0.00000096	0.00000005	27593.76581328	358.20	0.0001

Bounds on condition number: 1.11938, 4.47752

Table 47. Prediction Model with 3 Variables

Step 3 Variable PROSF Entered R-square = 0.82952959 C(p) = 4.36466199

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	29606.26252369	9868.75417456	131.39	0.0001
Error	81	6084.16100572	75.11309884		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	2.85272366	1.61180144	235.29462731	3.13	0.0805
CONSIZ	-0.00000002	0.00000001	262.14047302	3.49	0.0654
PROSF	0.00001427	0.00000811	232.63853627	3.10	0.0822
PRAMT	0.00000084	0.00000009	7055.96398144	93.94	0.0001

Bounds on condition number: 3.352469, 23.43771

Table 48. Prediction Model with Four Variables

PREDICTION MODEL FOR ESTIMATED TOTAL NUMBER OF ACCIDENTS

Step 4 Variable PROSTO Entered R-square = 0.83481557 C(p) = 3.84169143

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	4	29794.92131860	7448.73032965	101.08	0.0001
Error	80	5895.50221081	73.69377764		
Total	84	35690.42352941			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	2.12218303	1.66050713	120.36909830	1.63	0.2049
CONSIZ	-0.00000002	0.00000001	386.80215458	5.25	0.0246
PROSF	0.00001341	0.00000805	204.62776680	2.78	0.0996
PROSTO	0.48926558	0.30578878	188.65879491	2.56	0.1135
PRAMT	0.00000082	0.00000009	6723.82512855	91.24	0.0001

Bounds on condition number: 3.367376, 37.13299

All variables in the model are significant at the 0.1500 level.
No other variable met the 0.1500 significance level for entry into the model.

Table 49. Summary of Stepwise Regression Analysis

Summary of Stepwise Procedure for Dependent Variable TOTAC

Step	Variable Entered	Variable Removed	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	PRAMT		1	0.8172	0.8172	6.2383	371.1065	0.0001
2	CONSIZ		2	0.0058	0.8230	5.4758	2.6816	0.1053
3	PROSF		3	0.0065	0.8295	4.3647	3.0972	0.0822
4	PROSTO		4	0.0053	0.8348	3.8417	2.5600	0.1135

It is worth noting that another base model could be developed using one variable, that of project amount or contract amount (PRAMT). This is because it has been demonstrated in the case study that contract amount is indeed the most important single factor in predicting construction site accidents. However, after considering other statistical factors such as Mallow's theory and the fact that none of the remaining independent variables met the required level of significance, the model with three variables was selected. After the selection of the model was completed, it was checked for collinearity. No significant level of collinearity was found in the independent variables used. The results of this analysis are provided in Appendix J.

Discussion

Statistical Procedures

The development of the model presented from the results of the case study was done with the aid of the SAS software. The multiple regression analysis was selected in developing a model using the data from the case study. Other more complex statistical methods could have been used, but the multiple regression technique was selected for several reasons. First, it is as good as any of the other methods, especially when it is considered that simplicity was one of the criteria established for the development of the model approach. Secondly, the main objective of this study was the development of a

general concept and methodology. Therefore no attempt was made to develop new, or apply existing and more sophisticated, or more complex statistical theories.

A first order model was assumed for the relationship between the response variable and the independent variables because this type of model made intuitive sense. Furthermore, the analysis of the residuals plotted against the independent variables in the model indicated that no quadratic effects were present.

In using the method of least squares, in the regression the analysis, for the development of the illustrative prediction model presented as part of the case study, the following additional assumptions were made

1. The distribution for the total number of accidents is normal. In situations where the distribution is not normal (i.e., when it is Poisson, binomial, exponential, etc.), then other techniques such as log transformations or maximum likelihood estimation (MLE) should be explored. In such cases, the generalized linear model (GLIM) software may be used to develop models. However, it should be pointed out that the MLE technique is more complicated than the method of least squares and the GLIM software may be more difficult for contractors to use than SAS. A description and a simple example of the MLE technique is provided in Appendix K.

2. The number of accidents are independent from project to project, i.e. every project is independent from every other project even if the same contractor is working on those projects.
3. The variance is the same (constant) for all levels of the independent variables in the model.

Biases

In addition to the above assumptions, it should be pointed out that some biases may exist in the dataset used in the case study. These biases may have some effect on the final model developed. Therefore future researchers and others interested in the prediction of construction site accidents should be aware of biases when designing the research project, collecting and analyzing the data. For instance, in the case study presented in this research, the following are examples of potential biases that may exist in this research:

1. Nonresponse bias. As previously mentioned, the data used in the case study were collected from only those contractors who had consented to participate in the research. There were contractors who declined to participate. If the declining contractors had provided accident data, there is a good chance that the model developed would have been different. Therefore it may be argued that some nonresponse bias exists in the model developed.

2. Geographical bias. The data used in the case study were collected from contractors in four Florida counties. There is the possibility of the existence of a geographical bias in the model developed since there may be some homogenous conditions or factors in those four counties that may be common to the contractors who participated in the study. These conditions may not be present in other parts of Florida.
3. Size bias. This study was nonexperimental with unequal numbers of different sizes of contractors and projects chosen at random, as opposed to a designed or experimental study where equal numbers of all the various sizes of contractors and projects would have been selected. As a result, the number of large size contractors in the study was more than the smaller ones. Therefore, a good case can be made that there is a size bias, in the dataset of the case study towards large contractors.

In most cases, the problem of biases can be resolved by selecting truly representative or random samples. While some biases can be controlled by the proper inclusion of samples in the study, realistically, it is not always possible to select truly representative samples from the universe of interest. For example, in this study, the researcher, had no control over contractors who elected not to participate. As such, he was limited to, and he included all the contractors

who had consented to be a part of the study. By doing so, the dataset included different sizes of contractors and projects.

While it is strongly recommended that all efforts be made to control biases, whenever possible, it is also worth noting that the existence of biases in a study should not make a study invalid. As pointed out by Marks (1982):

> The fact that a representative sample cannot be chosen does not invalidate the research or serve as an unfair criticism of your work. However, you must realize that the inferences drawn may have some limitations and you should to identify the potential biases that may be introduced to the response variable because of the lack of complete representation. (p. 100)

In some studies a researcher may face circumstances under which it is difficult to choose a representative sample from the universe of interest. In such cases it is recommended that the major potential biases that may exist be clearly identified so that the researcher, future researchers, as well as others who may use the study can realize that the inferences drawn from the results of the study may have some limitations.

Model Verification

It is important that prediction models be field-tested on other projects before being applied in the construction industry. Tests performed on the illustrative model, developed in the case study using the original dataset and presented in Appendix L, appeared to show reasonable prediction of the actual number of accidents. However, for more precise testing, it is recommended that a new (different) dataset or other methods such as cross-validation estimates (a process where

a portion of the dataset is used for estimating the parameters of a model and the remainder of the dataset is used to calculate prediction errors) be used.

Summary

An approach for developing commercial construction accident prediction models was developed in this research. A case study was presented to illustrate the practical application of the methodology developed. The results of the case study indicated that the single most significant factor for predicting accidents is the amount (size) of the contract. However, using basic statistical guidelines, a model consisting of three independent variables--size of contractor (based on average annual volume for the past five years), square foot area of the building and the contract amount--was selected as the base model. The model developed in the case study was based on a sample of 85 projects from four counties in Florida, using a limited database of 1078 past accidents, and was intended only as an illustration of the approach developed in this research. Therefore the resulting model presented in this chapter must not be construed as a universal construction accident prediction model. However, it is hoped that the approach presented in this study can serve as a basis for future research and also serve as a model for developing construction accident prediction models for other parts of the country and other categories of construction projects.

CHAPTER 7

SUMMARY AND CONCLUSIONS

Introduction

The construction industry continues to have the highest rate of injury among major industries. With a rate of injury estimated to be 54% higher than the rate for all other industries, the construction industry is considered as one of the most dangerous places to work (Business Roundtable, 1982). Even though the high rate of accidents every year translates into billions of dollars in economic losses for the construction industry, the cost of the toll in human lives, suffering, misery and illnesses caused by these accidents is incalculable. Most safety experts feel that the number of construction accidents can be controlled and reduced. A tool that can help the industry to predict the number of accidents to be expected on a project can help control and prevent accidents.

In spite of the existence of a reservoir of information on past accidents, predicting construction site accidents can be difficult because of the following reasons:

a). The nature of the industry. The construction process is very dynamic. Each project is different and has its own set of unique conditions and factors.

b). Varying factors. There are many factors that have been known to influence or contribute to accidents at construction sites. However, these factors are as dynamic as the construction process, and are therefore subject to change from one project to the other.

c). Inadequate records. The reservoir of information on construction accidents available from the National Safety Council, the Occupational Health and Safety Ad ministration, Insurance Companies and other sources have been collected mainly for insurance purposes historically. As a result, the vast majority of the information available from these individual sources, often do not readily include all of the factors that can help in the prediction of accidents without additional research.

Because of the above reasons, using traditional methods of prediction, such as historical averages can provide inaccurate and misleading information. Therefore the approach developed in this research offers the construction and insurance industries, as well as the government and other owners of construction projects, an innovative alternative to scientifically predict the number of accidents on future commercial construction projects.

Research Objectives

This research focused on developing a systematic approach that can be used by engineers, construction personnel, safety experts, insurance companies, OSHA and other researchers to collect and analyze construction accident data, in order to develop models that can predict the number of accidents at construction sites; presenting the concept in a form such that it can be easily understood and used by construction and safety personnel, and used by future researchers as a basis for developing other models; and developing a model as part of a case study using data collected from actual construction projects.

Summary

The objectives of this research were accomplished by investigating the major factors that have been known to contribute to the occurrence of accidents, determining which of these factors are significant and available, and fitting the factors into a statistical model. The development of the model approach began with a literature review of previous relevant work as well as a background of safety in the construction industry. This was essential in understanding the construction process and the factors to be considered. This was followed by the methods and procedures to be used in conducting the study. A five-phase approach was developed using these methods and procedures. The first phase deals with identifying and listing of preliminary factors that are known

to influence accidents at construction sites. The input of contractors, OSHA and construction safety experts was crucial in identifying the influencing factors.

The second phase involves the collection of data. Great care should be exercised in designing a data collection scheme that can be implemented effectively to obtain the required data. It is also important that a clear distinction be made between desirable data which is not available and that which is significant and can be obtained from available sources.

Analysis of the collected data and the development of a prediction model follows in the third phase. This involves the application of statistical regression techniques to a database consisting of observational, but nonexperimental accident data. Demonstration of the approach developed with a case study Presentation of an accident predicting model concludes the research. The model approach developed from this study is illustrated in a schematic flow chart in Figure 4.

Accident Prediction Model

The model developed was expressed as

$$Y = 3 + [-(0.00000002)(X_1)] + (0.00001427)(X_2) + (0.00000084)(X_3)$$

where

Y = ENAPPRO (estimated number of accidents per project)

3 = estimate of intercept (from regression analysis and rounded to a whole number)

-0.00000002 = estimate of slope for the variable, size of contractor size (CONSIZ) from regression analysis

X_1 = size of contractor (average of annual volume for the past five years)

0.00001427 = estimate of slope for the variable, project square foot (PROSF) from regression analysis

X_2 = size of building (square footage)

0.00000084 = estimate of slope for the variable, project amount (PRAMT) from regression analysis

X_3 = size of contract

Applications of the model approach

Although the data used in the development of the model were collected from 4 Florida counties, the methodology and procedure developed in this study is detailed enough to facilitate the development for similar models for other parts of the country, with minor modifications and considerations for the local statistical data and independent variables.

Secondly, this model can be used by the construction industry to predict the number of accidents to be expected on each individual project by various contractors in order to

a). screen contractors during the bidding process and prior to contract award by using the number of accidents as part of the criteria in choosing safe contractors. This can be done by selecting the contractor with the lowest

number of expected accidents on a project by project basis, or by eliminating those with high number of predicted accidents.

b). Establish insurance reserves on a project by project basis. For instance, the reserves for a construction firm on a project where the predicted number of accidents is 8 should be less than one on which the predicted is 22.

c). Assist in the realistic evaluation and modification of safety programs to make them more effective on future projects. By comparing the total number of accidents predicted at the beginning with the actual number of accidents at the end of projects, a determination can be made as to the effectiveness of a safety program.

d). Estimate the level of risk before underwriting surety bonds or insurance policies for contractors. This can be accomplished by insurance companies using the model approach to determine the number of accidents to be expected on each project, and then assigning different levels of risk to contractors for specific projects.

In addition to the above, the model approach presented in this dissertation can serve as the basis for future research in developing other models that are capable of predicting the logistical details (such as the type and severity) of the total number of accidents.

Conclusions

The investigation conducted during this research revealed that several factors contribute significantly to the number of accidents at construction sites. The most significant factors include the size of a contractor, the size of a building (square foot area) and the size of a project (contract amount). Because the emphasis of this study was on project related variables, other known factors such as project design, health and other characteristics of construction workers, the type and severity of resulting accidents received no consideration. These are major areas each of which requires extensive research and study.

The concept developed here is offered as the foundation, a "benchmark" that can be utilized by researchers as a prototype to develop models for other types of construction projects. The results obtained through the development of this concept would permit the construction industry, the insurance industry, government and safety experts to design, modify and implement accident prevention plans, tailored to specific projects and contractors, and thereby help reduce the number of accidents at construction sites.

It is important to note that because of the dynamic nature of the construction industry and process, the development of an accident prediction should be a continuous undertaking. As new projects are completed, observational data

should be collected and the database with the resulting models updated to include the latest data.

Finally, it should be mentioned that even though the data used for this study were from commercial construction projects, the concept developed can be applied to other categories of construction, such as highway construction and industrial construction with minimum modifications. Although the influencing factors will be different, due to the unique nature of each category of construction project, the principles of the concept will be the same.

Recommendations for Future Research

During the course of the research for this study, several areas that needed further study were identified. These areas include

1. Revision of the First Notice of Injury Form. The collection of meaningful data is a key part of the development of a prediction model. The form presently used for recording construction site accident data is oriented towards information needed mostly for insurance purposes. The present form is not designed to collect information about the contractor (size, experience, etc.) and the project (size, contract amount, location, phase of the project where an accident occurred, the number of people on site at the time of the accident, etc.) and other desirable data. A great deal of basic research needs to

be done to either develop a new form that will capture this type of data in addition to the insurance type of data, or revise the existing form to accomplish this task.

2. <u>Development of commercial construction site accident prediction models at the State, Regional and National Levels</u>. The concept developed in this study and the resulting model was based on data collected from a limited sample of 85 projects in four Florida counties. There is a need to conduct research, using the approach developed and a more extensive database to derive and field-test prediction models at the state, regional and national levels.

3. <u>Development of construction site accident prediction models for other categories of construction.</u> Research should be conducted, using the methodology developed in this study, to determine the variables associated with the other remaining categories of construction in order that models can be developed for those categories. Even though the independent variables for other categories of construction (such as heavy and highway construction, industrial construction, etc.) will be different from those of the commercial construction industry, the model approached developed in this research can be applied to develop similar accident prediction models for those other categories of construction.

4. Prediction of the severity of accidents. There is a need for an in-depth study to investigate the possibility of developing models that will predict the severity of accidents. The database used in this research included random combinations of various accidents ranging from simple ones, such as foreign object in eye or a small cut on the finger, to more serious accidents. There is a need to conduct further research to determine if weighting factors (in terms of severity) can be introduced into models in order to predict the severity of the accidents. It is anticipated that a study of this type will require revised forms to collect logistical data, the willingness of contractors participating in the research to maintain the required files and more complex logistic type statistical modelling techniques. It is also anticipated that because of the large number of terms involved and the size of the equation which would be generated, it may be necessary to use a more powerful software (such as the "S-plus" recently developed by Bell laboratories for AT&T) capable of performing the resulting complex regression analysis.
5. Application of Artificial Intelligence Techniques. Several of the processes used and developed in this study, such as the selection of parameters, the development of models as well as the prediction of accidents on future projects can be greatly enhanced by the use

of artificial intelligence techniques. This is an area that the researcher intends to pursue in the future, pending the availability of research funding.

6. Development of other models. Using the approach demonstrated in this study, other models can be developed to predict the probability of a single person, group of people or individuals of certain specific trades getting into accidents at construction sites, using logistic re-regression analysis techniques.

7. Application of advanced and complex statistical techniques. Even though a general basic statistical method (the method of least squares) was used in this research for simplicity and it worked well, there is a need to conduct additional research using other more advanced and sophisticated techniques such as the Maximum Likelihood Estimation method. These other techniques can be utilized in order to determine whether or not they enhance the precision of construction site accident prediction model developed in this research.

8. Prediction of types of accident. There is a need to conduct further research in order to develop models for predicting the types of accidents to be expected at construction sites using other statistical techniques such as the Maximum Likelihood Estimation (MLE) method. This may require special arrangements, in advance with contractors, under designed research conditions in order

to collect additional data that was not readily available in a nonexperimental type of research.

The model approach developed and demonstrated in this dissertation is still in an evolutionary state and can be regarded as a test tube model that is offered as a basis for further study. The author's attention in this research was limited to developing a methodology that can lead to the derivation of models to predict an estimated (average) number of accidents to be expected on commercial construction projects. As defined by McNeil et al. (1975):

> Prediction is the process of using data from a smaller group (sample) of measurable entities to make estimates about a larger group (population) from which such data has not been gathered. (p. 3)

Acceptable results were obtained using a simple linear model. No attempt was made to develop other types of models to forecast further details of the expected number of accidents being predicted (such as severity and type of accident, the age, sex, race, trade, and the length of employment of the injured worker). This was due to the fact that the data required for such predictions were not readily available. In addition, such predictions may require the application of logistical, or perhaps other more sophisticated and advanced statistical techniques that are beyond the scope of this study. These subjects in themselves require extensive study, and are potential areas for future funded research.

Finally, it is hoped that this research and the model approach developed has presented the construction industry with an innovative tool that can play a significant role in finding solutions to one of its biggest problems--the high number of construction site accidents. It is also hoped that this dissertation has provided the construction industry with a methodology for developing gauges (predicted number of accidents) against which the effectiveness of many existing safety programs can be measured on a job-by-job basis, and evaluated so that further improvements can be made to prevent accidents from happening.

APPENDIX A

EXAMPLE OF PRELIMINARY DATA COLLECTION FORM

SCHOOL OF BUILDING CONSTRUCTION, UNIVERSITY OF FLORIDA

BUILDING CONSTRUCTION SITE ACCIDENT DATA COLLECTION FORM

A. PROJECT INFORMATION

1. PROJECT NAME OR DESCRIPTION :______________________________
   (e.g. Civic Center, Hotel, Office Building, Hospital, Warehouse, Shopping Center, Mall, Renovation, etc.)

2. LOCATION : City __________________ Urban __ Suburban ____

3. SIZE: Square Footage ______________________

   No. of Stories __________

   Contract Amount $______________________

4. CONTRACT DURATION: ____________Months

5. TYPE OF STRUCTURE: Reinforced Concrete ____
   Structural Steel ____
   Masonry ____
   Wood ____
   Combination (Conc. & Steel) ____
   Other______________________________
   (Please Specify)

6. NUMBER OF SUBCONTRACTORS:_____________

7. APPROXIMATE # OF WORKERS ON SITE ___________________

B. ACCIDENT INFORMATION

TYPE OF ACCIDENT

1. Struck against, rubbed or abraded ___
2. Struck by ___
3. Caught in, under or between ___
4. Fall on same level ___
5. Fall to different level ___
6. Overexertion or bodily reaction ___
7. Contact with temperature or pressure extremes ___
8. Contact with radiation, caustics, & toxic substances ___
9. Contact with electric current ___
10. Stepped on object (nail, wire, etc.) ___
11. Foreign object (______________) in eye ___
12. Cut by ___
13. Other____________________________ ___

TYPE OF WORK BEING PERFORMED: ______________________________
(At the time of accident)

DATE OF ACCIDENT:_________ (Day/Mon./Y.r); Time of Accident

PHASE OF PROJECT: Substructure __; Superstructure__ ;
Ext. Closure__ ; Roofing __ ;
Interior Work__ ; Sitework__ ;

AGE OF INJURED WORKER:______Years.; # OF LOST DAYS ____ Days

OCCUPATION: ___Foreman ___Carp. ____Carp. Appr./Helper

___Cem. Fin. ___Ironworker ____Rodbuster

___Eqip. Oper. ___Laborer __Other

EMPLOYED BY: Gen. Cont.__ ; Sub.__; # OF YRS. IN BUS.___Yrs.

LENGTH OF EMPLOYMENT PRIOR TO ACCIDENT:__Yrs.__Mo.__Wk. __Days

MEDICAL COSTS (If available):

APPENDIX B

EXAMPLE OF DEPARTMENT OF LABOR DATA

Disabling Work Injuries by Major Industry by Type of Disability
Florida, 1985

	TEMPORARY TOTAL	PERMANENT IMPAIRMENT	TEMPORARY PARTIAL	PERMANENT TOTAL	HERNIA	FATAL	FATALITY NATURAL CAUSES	TOTAL
TOTAL	80,749	1,862	2,799	22	1	130	0	85,563
AGRICULTURE, FORESTRY & FISHING	4,512	136	167	0	0	16	0	4,831
MINING	186	10	5	0	0	1	0	202
CONTRACT CONSTRUCTION	16,260	521	639	6	0	35	0	17,461
MANUFACTURING	11,080	275	306	2	1	14	0	11,678
TRANSP., COMM.& OTHER PUB. UTIL.	5,452	110	141	2	0	14	0	5,719
WHOLESALE AND RETAIL TRADE	19,791	406	729	4	0	19	0	20,949
FINANCE, INSURANCE & REAL ESTATE	2,543	49	174	2	0	2	0	2,770
SERVICES	11,908	267	494	1	0	18	0	12,688
GOVERNMENT	8,999	88	143	5	0	11	0	9,246
NONCLASSIFIABLE ESTABLISHMENTS	18	0	1	0	0	0	0	19

Disabling Work Injuries by Accident Type and Industry
Florida, 1985

INDUSTRY 1/	TOTAL	STRUCK AGAINST RUBBED ABRADED JUMPS	STRUCK BY	CAUGHT IN, UNDER OR BETWEEN	FALL ON SAME LEVEL	FALL TO DIFFERENT LEVEL	OVEREXERTION OR BODILY REACTION	CONTACT WITH TEMPERATURE EXTREME	CONTACT WITH RADIATIONS CAUSTICS	CONTACT WITH ELECTRIC CURRENT	AIRCRAFT & MOTOR VEHICLE	OTHER AND NOT REPORTED
BLDG. CONSTRUCTION, GEN. CONTR.	2,769	315	353	84	204	337	609	22	23	10	34	778
GENERAL BUILDING CONTRACTORS	2,736	310	346	83	204	335	600	22	23	10	33	770
GEN. CONTR., OTHER THAN BLDG.	2,343	284	332	101	132	219	494	31	24	7	101	618
HIGHWAY & STREET CONSTRUCTION	942	112	126	35	60	101	188	18	11	1	49	241
HEAVY CONSTRUCTION	1,399	172	205	66	72	118	305	13	13	6	52	377
CONSTRUCTION, SPEC. TRADE CONTR.	12,349	1,495	1,378	364	759	1,785	2,702	225	97	51	223	3,270
PLUMBING, HEATING, ETC.	1,425	194	145	26	91	173	364	14	6	6	33	373
PAINTING & PAPER HANGING	565	58	48	10	35	128	109	4	6	3	11	153
ELECTRICAL WORK	1,375	172	137	36	76	217	327	18	8	21	31	332
MASONRY, STONEWORK, & PLASTERING	1,295	140	143	35	70	195	308	6	18	2	17	361
CARPENTERING & WOOD FLOORING	2,884	364	388	94	173	418	579	12	11	5	29	811
ROOFING & SHEET METAL WORK	1,348	150	114	40	77	220	251	142	15	3	21	315
CONCRETE WORK	1,126	125	141	37	78	120	255	9	11	6	20	324
WATER WELL DRILLING	50	9	8	7	2		12			1	3	8
MISC. SPECIAL TRADE CONTRACTORS	2,248	279	252	77	157	310	490	17	21	3	57	585
MANUFACTURING	11,678	1,530	1,900	859	822	638	2,736	116	114	25	226	2,712
ORDNANCE AND ACCESSORIES	69	7	3	4	11	3	23	2	2	1		13
AMMUNITION, EXCEPT SMALL ARMS	60	4	3	3	11	3	21	2	2	1		10
SIGHTING & FIRE CONTROL EQUIP	3	1		1								1
SMALL ARMS	3	2										1
SMALL ARMS AMMUNITION	3						2					1
FOOD AND KINDRED PRODUCTS	3,261	544	849	107	218	182	637	42	31	3	75	573
MEAT PRODUCTS	217	39	23	13	14	10	54	5	1		9	49
DAIRY PRODUCTS	110	10	8	6	12	12	37	4	2		1	18
CANNING & PRESERVING	425	51	25	31	51	43	96	7	6	2	24	89
CANNED CITRUS FRUITS AND JUICES	127	11	4	11	12	14	29	5	3	2	5	31
FROZEN CITRUS FRUITS & JUICES	136	12	7	9	14	23	36		1		12	22
GRAIN MILL PRODUCTS	54	4	5		6	2	9				8	20
BAKERY PRODUCTS	152	17	10	13	16	6	34	1			5	50
SUGAR	1,909	398	739	25	93	76	266	16	21	1	24	250
CONFECTIONERY & RELATED PRODUCTS	7			1		1	1	2				2
BEVERAGE INDUSTRIES	282	15	29	13	14	19	113	4			3	72
MISCELLANEOUS FOOD PRODUCTS	101	9	9	5	11	13	27	2	1		1	23
TOBACCO MANUFACTURES	51	12	10	5	4	2	9		2			7
CIGARETTES	1					1						
CIGARS	49	12	10	4	4	1	9		2			7
TEXTILE MILL PRODUCTS	54	12	6	5	2		12	1			2	14
BROAD WOVEN FABRIC MILLS, COTTON	2						1				1	
NARROW FABRICS	1											1

Work Injuries, Days of Disability and Cost by Industry
Florida, 1985

INDUSTRY 1/	S I C CODE 2/	DISABLING NO. OF INJURIES	DAYS LOST	MEDICAL COST	COMPENSATION	TOTAL COST
BLDG. CONSTRUCTION, GEN. CONTR.	15	2,769	140,708	8,411,413	8,230,093	16,641,506
GENERAL BUILDING CONTRACTORS	151	2,736	137,826	8,323,150	8,035,296	16,358,446
GEN. CONTR., OTHER THAN BLDG.	16	2,343	148,538	11,489,597	6,771,528	18,261,125
HIGHWAY & STREET CONSTRUCTION	161	942	66,369	7,980,918	2,740,180	10,721,098
HEAVY CONSTRUCTION	162	1,399	82,121	3,505,896	4,030,541	7,536,437
CONSTRUCTION, SPEC. TRADE CONTR.	17	12,349	687,129	51,330,651	40,980,169	92,310,820
PLUMBING, HEATING, ETC.	171	1,425	76,555	4,226,869	4,578,524	8,805,393
PAINTING & PAPER HANGING	172	565	36,961	2,017,879	2,321,298	4,339,177
ELECTRICAL WORK	173	1,375	77,511	11,093,510	4,215,948	15,309,458
MASONRY, STONEWORK, & PLASTERING	174	1,295	71,279	3,553,512	3,292,933	6,846,445
CARPENTERING & WOOD FLOORING	175	2,884	149,661	8,074,544	8,113,457	16,188,001
ROOFING & SHEET METAL WORK	176	1,348	63,523	11,467,431	5,277,622	16,745,053
CONCRETE WORK	177	1,126	58,351	3,490,897	4,562,585	8,053,482
WATER WELL DRILLING	178	50	7,307	106,999	83,938	190,937
MISC. SPECIAL TRADE CONTRACTORS	179	2,248	142,826	7,101,024	8,273,329	15,374,353
MANUFACTURING		11,678	491,372	24,473,935	24,190,097	48,664,032
ORDNANCE AND ACCESSORIES	19	69	2,042	122,326	229,465	351,791
AMMUNITION, EXCEPT SMALL ARMS	192	60	1,904	116,484	225,264	341,748
SIGHTING & FIRE CONTROL EQUIP	194	3	21	1,551	161	1,712
SMALL ARMS	195	3	65	291	856	1,147
SMALL ARMS AMMUNITION	196	3	52	4,000	3,184	7,184
FOOD AND KINDRED PRODUCTS	20	3,261	95,632	4,045,527	4,984,385	9,029,912
MEAT PRODUCTS	201	217	7,631	485,397	1,191,681	1,677,078
DAIRY PRODUCTS	202	110	4,329	330,325	387,704	718,029
CANNING & PRESERVING	203	425	28,744	907,971	887,905	1,795,876
CANNED CITRUS FRUITS AND JUICES	3/	127	3,794	176,400	129,430	305,830
FROZEN CITRUS FRUITS & JUICES	3/	136	13,175	382,426	297,606	680,032
GRAIN MILL PRODUCTS	204	54	1,989	99,862	123,594	223,456
BAKERY PRODUCTS	205	152	5,285	291,825	346,870	638,695
SUGAR	206	1,909	34,551	1,139,313	1,140,575	2,279,888
CONFECTIONERY & RELATED PRODUCTS	207	7	122	6,118	1,793	7,911
BEVERAGE INDUSTRIES	208	282	9,971	670,394	775,328	1,445,722
MISCELLANEOUS FOOD PRODUCTS	209	101	2,843	111,320	122,402	233,722
TOBACCO MANUFACTURES	21	51	2,444	91,732	166,503	258,235
CIGARETTES	211	1	8	315	28	343
CIGARS	212	49	2,413	89,666	165,723	255,389
TEXTILE MILL PRODUCTS	22	54	1,246	273,626	127,142	400,768
BROAD WOVEN FABRIC MILLS, COTTON	221	2	35	3,184	1,228	4,412
NARROW FABRICS	224	1				

1/20/89

RZ101 MAJOR INDUSTRY CODES 15-17/YEARS 82-85/COUNTIES 16,29,48,52

EMP NAME		CO	DOA	SIC	TYPE	NATURE	BODY	AGE	COMP	MED	SSN
BANNON PAINTING INC 4336 MILLBROOK AVENUE #13	TAMPA	29	85/12/30 FL 33611	172	99	61	37	36	14,151	9,044	263-98-7377
BARLERY U H INC 8606 N 40TH ST	TAMPA	29	82/06/21 FL 33604	175	01	61	02	32	1,920	170	262-29-0070
BARBERY O H INC 8606 N 40TH ST	TAMPA	29	84/02/27 FL 33604	175	00	00	00	4	0	0	261-19-6799
BARCIA X RAY CO INC 5305 W CRENSHAW AVE	TAMPA	29	84/09/05 FL 33614	173	51	61	37	61	73	4,092	116-24-1571
BARNES NEWTON T JR GENERAL CONTRACT P O BOX 8468	JAX	29	83/03/03 FL 32211	175	00	00	00	0	0	0	100-32-9810
BAROCO ELECTRIC CONSTRUCTION 3605 N DAVIS ST/PO BOX 17269	PENSACOLA	29	84/03/28 FL 32522	173	31	61	91	23	360	269	590-18-6667
BAROCO ELECTRIC CONSTRUCTION 3605 N DAVIS ST/PO BOX 17269	PENSACOLA	29	84/06/07 FL 32522	173	00	00	00	24	664	397	261-47-4784
BAROCO ELECTRIC CONSTRUCTION 3605 N DAVIS ST/PO BOX 17269	PENSACOLA	29	84/08/15 FL 32522	173	14	20	21	31	160	3,206	182-50-9800
BAROCO ELECTRIC CONSTRUCTION 3605 N DAVIS ST/PO BOX 17269	PENSACOLA	29	85/01/11 FL 32522	173	51	61	37	37	60	28	263-94-4309
BAROCO ELECTRIC CONSTRUCTION 3605 N DAVIS ST/PO BOX 17269	PENSACOLA	29	85/04/25 FL 32522	173	51	61	36	25	63	104	263-59-0406
BAROCO ELECTRIC CONSTRUCTION 3605 N DAVIS ST/PO BOX 17269	PENSACOLA	29	85/04/26 FL 32522	173	22	71	69	29	635	290	261-47-4789
BAROCO ELECTRIC CONSTRUCTION 3605 N DAVIS ST/PO BOX 17269	PENSACOLA	29	85/07/09 FL 32522	173	51	61	37	3	2,040	1,589	573-41-6052
BARRON GENE FILL DIRT & HAULING 3904 AIRPORT RD	PLANT CITY	29	84/06/05 FL 33566	161	51	61	09	24	616	684	264-91-1651
BARROSO HENRY PAINTING CONTRACTOR 4704 W EUCLID STREET	TAMPA	29	82/05/05 FL 33609	172	43	20	47	46	1,568	707	267-64-1653
BARROSO HENRY PAINTING CONTRACTOR 4704 W EUCLID STREET	TAMPA	29	83/07/22 FL 33609	172	00	00	00	5	0	0	291-36-9569
BARROSO HENRY PAINTING CONTRACTOR 4704 W EUCLID STREET	TAMPA	29	84/05/07 FL 33609	172	43	71	39	4	96	417	265-21-3801
BASS MASONRY INC 13325 SEMINOLE TRAIL	WILLOW SHOR	29	82/03/26 FL 33598	174	11	71	92	23	72	316	267-45-7066
BASS MASONRY INC 13325 SEMINOLE TRAIL	WILLOW SHOR	29	84/12/05 FL 33598	174	00	00	00	4	0	0	261-67-1774

APPENDIX C

EXAMPLE OF AN INSURANCE COMPANY FORM

S. HAMMOND STORY AGENCY, INC.

A SUBSIDIARY OF

ALEXANDER & ALEXANDER INC.

404-266-0560

SUITE 600, ONE PIEDMONT CENTER • 3565 PIEDMONT ROAD, N. E. • ATLANTA, GEORGIA 30305

July 13, 1989

Professor K. Bentil
School of Building Construction
FAC 101
University of Florida
Gainesville, Florida 32611

Dear Professor Bentil:

Per your conversation with Gary O'Neal of this office, enclosed is a loss forecasting form.

Please let us know if we can be of any further assistance.

Sincerely,

Susan R. Brock

Susan R. Brock

SB/sr

Enclosure

Anistics Inc.
Piedmont Center
Piedmont Road

√Anistics

Subsidiary of Alexander & Alexander Inc.

NAME OF ACCOUNT	NAME OF PRODUCER
ADDRESS	ADDRESS

EXPOSURE ANALYSIS	3rd subsequent year	2nd subsequent year	1st subsequent year	current year	1st prior year	2nd prior year	3rd prior year	4th prior year
Fiscal Period								
Total Payroll								
Total Employees or Hours Worked								
Total Receipts								
No. Vehicles								

LOSS ANALYSIS	current year	1st prior year	2nd prior year	3rd prior year	4th prior year
Workers' Compensation Valuation Date					
Paid Losses					
Outstanding Losses					
Total Incurred					
Number of Claims : Indemnity					
Medical Only					
General Liability Valuation Date					
Paid Losses					
Outstanding Losses					
Total Incurred					
Number of Claims					
Automobile Liability Valuation Date					
Paid Losses					
Outstanding Losses					
Total Incurred					
Number of Claims					
Auto Physical Damage Valuation Date					
Total Incurred					
Number of Claims					

PLEASE ATTACH AN ANNUAL STATEMENT IF AVAILABLE.

ESTIMATED CURRENT PREMIUMS				
STATE	WORKERS' COMPENSATION	GENERAL LIABILITY	AUTOMOBILE LIABILITY	AUTOMOBILE PHYSICAL DAMAGE

Describe any outside influences which would effect forecasted loss levels. (acquisitions, deletions, changes in product mix, strikes, corporate growth plans, etc.)

INDIVIDUAL LOSSES IN EXCESS OF $25,000

Policy year	Date of Loss	Coverage	Open = O Closed = C	Amount	Description

APPENDIX D

EXAMPLE OF NCCI DATA

Ratemaking Exhibits Industrywide Data

Miscellaneous Statistical Plan Data

These exhibits show classification experience by state, hazard group, industry group, class code and year; including premium and losses by injury type.

Loss Development Factors

Development factors by state, based on benefit costs, are available on either an accident year or policy year basis; paid or incurred; IBNR included or excluded (six variations possible).

Loss Payout Patterns

These exhibits provide a history of loss payout, using the latest policy year data, on a state-by-state basis.

Rate Table Data Tapes

Rate table data tapes aid in computer issuance of policies. They reflect approved rates and rating values as written in NCCI approval circulars, and are distributed automatically within seven days after the circular's release to announce revised rates and rating values applicable to the state, or upon request, at the option of the carrier.

CLAIMS COST ANALYSIS

In order to analyze claims in a more detailed fashion than statistical plan data will allow, NCCI also conducts ongoing calls for Detailed Claim Information (DCI) which delve into the specifics of a claim. In-depth questions are asked about the incident, the claimant and surrounding circumstance, making it possible to analyze the causal factors associated with workers compensation claim costs.

Customized Detailed Claim Information (DCI) Analysis

This exhibit provides customized reports produced from the DCI data base, analyzing claim cost statistics by factors such as body part and injury type. Other variables, such as subrogation, controversion, sex, attorney representation, vocational rehabilitation, benefit type, and/or duration, may be included in the analyses.

Workers Compensation Claim Characteristics

This publication provides an overview of claim characteristics, with a description of the Detailed Claim Information (DCI) data base, and samples of the types of reports available. It provides insight into the component costs of the workers compensation system in 13 selected states. It examines key issues, including claimant-attorney representation, occupational disease emergence and vocational rehabilitation activities.

APPENDIX E

EXAMPLE OF REVISED DATA COLLECTION FORM

SCHOOL OF BUILDING CONSTRUCTION, UNIVERSITY OF FLORIDA
COMMERCIAL CONSTRUCTION SITE ACCIDENT DATA COLLECTION FORM

A. CONTRACTOR INFORMATION (complete once for each contractor)

1. Number of years in business ______ years
2. Average annual volume (past five years) $________________

B. PROJECT INFORMATION (complete for each project with accident)

1. TYPE OF PROJECT:______________________________
   (e.g. hotel, office, parking deck, hospital, etc.)
2. CONTRACT DURATION ______________ Months
3. PROJECT START DATE:______________
4. PROJECT SIZE: Square footage____________________
   No. of stories____________________
   Contract Amount $__________________

5. TYPE OF STRUCTURE:

Reinforced Concrete	_____
Structural Steel	_____
Masonry	_____
Wood/Timber	_____
Combination (Conc. & steel)	_____
Other ______________________ (Please specify)	_____

C. ACCIDENT INFORMATION (complete for each project)

1. TOTAL NUMBER OF ACCIDENTS ON PROJECT:______________
2. SPECIFICS OF ACCIDENTS:

TYPE	NUMBER
a) Struck against, rubbed or abraded	
b) Struck by	
c) Caught in, under or between	
d) Fall on same level	
e) Fall to different level	
f) Overexertion or bodily reaction	
g) Contact with temperature or pressure extremes	
h) Contact with radiation, caustics & toxic substances	
i) Contact with electric current	
j) Stepped on object (nail, wire, etc.)	
k) Cut by	
l) Foreign object in eye	
m) Other (please specify ________________________)	

APPENDIX F

EXAMPLE OF FIRST NOTICE OF INJURY FORM

Notice of Injury

STATE OF FLORIDA
DEPARTMENT OF LABOR AND EMPLOYMENT SECURITY
Division of Workers' Compensation
1321 Executive Center Drive, East
Tallahassee, Florida 32301

ATTENTION: W.C. CLAIMS OFFICE
Phone: 1-800-342-1741

Report all deaths by telephone or telegram within 24 hours.

EMPLOYER INFORMATION

FIRM S NAME

MAILING ADDRESS (Including Zip Code)

TELEPHONE
Area Code Number

LOCATION ☐ Same as Mailing

NATURE OF BUSINESS

FEDERAL EMPLOYER I D NUMBER

EMPLOYEE INFORMATION

NAME (First, Middle, Last)

SOCIAL SECURITY NUMBER

HOME ADDRESS (Include Zip Code)

OCCUPATION

SUPERVISOR'S NAME

DEPARTMENT NAME

TELEPHONE
Area Code Number

DATE OF BIRTH

SEX ☐ M ☐ F

How long employed?

Number of hours worked ☐ Per Week ☐ Per Day

Number of days worked per week

RATE OF PAY ☐ Per Hour ☐ Per Day ☐ Per Week

If piece work or commission, enter average weekly amount

If board, lodging or other advantages furnished, enter weekly amount

WORKER'S COMPENSATION COVERAGE BY ☐ Insurance Company ☐ Self-Insured
GIVE NAME, ADDRESS AND POLICY NUMBER OF INSURANCE COMPANY OR SELF-INSURED SERVICE COMPANY

Policy No ____________

ACCIDENT INFORMATION

DATE AND TIME OF ACCIDENT

DATE AND TIME FIRST REPORTED

NAME, ADDRESS AND PHONE NUMBER OF PHYSICIAN

PLACE OF ACCIDENT (Street, City, County, State)

LAST DATE EMPLOYEE WORKED

RETURNED TO WORK ☐ Yes ☐ No

IF YES, DATE

Employee Paid for Date of Injury ☐ Yes ☐ No

PHYSICIAN AUTHORIZED BY EMPLOYER ☐ Yes ☐ No

NAME, ADDRESS AND PHONE OF HOSPITAL

EMPLOYEE MISSED ONE SHIFT, ONE DAY OR MORE? ☐ Yes ☐ No

WAS INJURY FATAL? ☐ Yes ☐ No If Yes, Date of Death

EMPLOYEE'S DESCRIPTION OF ACCIDENT (Give details such as fell, was struck, etc.)

DESCRIBE INJURY OR DISEASE AND INDICATE PART OF BODY AFFECTED (e.g. Amputation of right index finger at second joint, Fractured ribs, Lead Poisoning, etc.)

EMPLOYER I agree with this description? ☐ Yes ☐ No If no, explain in comments

COMMENTS:

Any person who, knowingly and with intent to injure, defraud or deceive any employer or employee, insurance company, or self-insured program, files a statement of claim containing any false or misleading information is guilty of a felony of the third degree

EMPLOYER (Read and Sign) ____________ SIGNATURE ____________ DATE

LES Form BCL 1 (Rev. 7/87) 532

EMPLOYEE (Read and Sign) ____________ SIGNATURE ____________ DATE

APPENDIX G

VALIDATED DATA COLLECTION FORM

COMMERCIAL CONSTRUCTION SITE ACCIDENT PREDICTION
DATA COLLECTION AND ENTRY FORM

A. CONTRACTOR CHARACTERISTICS

1. Experience in years [__________]

2. Size in thousands of dollars [$__________________]

B. PROJECT CHARACTERISTICS

1. Duration in months [__________]

2. Starting Date (month/year) [__________]

3. Size:

Number of stories [__________]

Building Area in square feet [__________________]

Contract Amount in thousands [$__________________]

C. ACCIDENT DATA

1. Total Number of Accident on project [_________]

2. Number of each accident type:

Struck against, rubbed or abraded	[_____]
Struck by	[_____]
Caught in, under or between	[_____]
Fall on same level	[_____]
Fall to different level	[_____]
Overexertion or bodily reaction	[_____]
Contact with temperature or pressure extremes	[_____]
Contact with radiation, caustics or toxics	[_____]
Contact with electric current	[_____]
Stepped on object (nail, wire, etc.)	[_____]
Cut by	[_____]
Foreign object in eye	[_____]

APPENDIX H

SAMPLE LETTERS OF APPRECIATION

SCHOOL OF BUILDING CONSTRUCTION
UNIVERSITY OF FLORIDA
GAINESVILLE, 32611

PHONE 904 392-5965
904 392-0202
SUNCOM 622-0202

December 14, 1989

Dear

This is to express my sincere appreciation to you for permitting me to review your firm's safety records as part of my research to help improve safety on construction sites. Your desire to participate in this research is a clear indication of your dedication to safety, and your continued interest and support of research that can benefit the construction industry as a whole.

The information provided by your staff was very helpful. I was also impressed not only with your firm's safety record and policies, but also the tremendous effort being put out by your Corporate Safety and Health Manager to make construction sites safer. The excellent results achieved by him in a short period of time is a vivid testimony of his efforts. This achievement was possible because of your recognition of the fact that safety should be a profit center in a construction firm.

Once again, thank you for your willingness to participate in this research. I will continue to work with to help develop some of his new but excellent ideas on improving safety at construction sites and furnish you a copy of the results of my research when completed.

Sincerely,

Kweku K. Bentil, AIC

SCHOOL OF BUILDING CONSTRUCTION
UNIVERSITY OF FLORIDA
GAINESVILLE, 32611

PHONE 904 392-5965
904 392-0202
SUNCOM 622-0202

December 18, 1989

Dear

This is to express my sincere appreciation to you, and the for permitting me to review your firm's safety records as part of my research to help improve safety on construction sites. Your willingness to participate in this research is a clear indication of your firm's dedication to safety, and continued interest and support of research that can benefit the entire construction industry. This is indeed a true testimony and example of how industry can support academe in finding solutions to problems.

I was also very impressed by safety record and policies as well as orderly fashion in which kept your safety records. She has and is still doing a commendable job in maintaining these records in such an organized manner. The information provided by you will contribute tremendously towards the successful completion of a much needed research.

Once again, thank you for your willingness to participate in this research. As promised, even though all the data collected will be aggregated with other data to provide complete anonymity of the source, a copy of the results of my research will be furnished to you upon completion.

Sincerely,

Kweku K. Bentil

Kweku K. Bentil, AIC

cc: Vice-President

SCHOOL OF BUILDING CONSTRUCTION
UNIVERSITY OF FLORIDA
GAINESVILLE, 32611

PHONE 904 392-5965
904 392-0202
SUNCOM 622-0202

February 22, 1990

Dear

This is to express my sincere appreciation to you for permitting me to obtain past accident data from as part fo my research to help improve safety on construction sites. Your consent to provide the above information for this research is a clear indication of your dedication to safety and your continued interest and support of research that can benefit the construction industry as a whole.

I was impressed with the commendable job being done by in maintaining your firm's accident and other related records in such an organized manner. was extremely helpful in providing me with information that will contribute tremendously towards the completion of my research.

Once again, thank you for your willingness to furnish information for this research. As promised, although all the data collected from will be aggregated with data from other constructors, a copy of the results of my research will be furnished to you upon completion of the study.

Sincerely,

Kweku K. Bentil

Kweku K. Bentil AIC

APPENDIX I

DATABASE OF ACCIDENT OBSERVATIONS

```
Options ps=60 nodate;
DATA ACDENTS;
INPUT CONID $1-2 CONEX 3-4 CONSIZ 6-9 TYPE 11-12 DUR 14-15 STDAT
17-20  PROSF 22-26 PROSTO 28-29 PRAMT 31-36 STRUCT 38-39 TOTAC
40-41  STRUG 43-44 STRUB 45-46 COTIN 47-48 FALSAM 49-50 FALDIF
51-52 OVEXT 53-54 COTEMP 55-56 COTOX 57-58 CONEL 59-60 STEPD
61-62 CUT 63-64 FOREYE 65-66;

CARDS;
A 22 22E7  7 11 1186 525E3  1 5567E4 5 60 24 9 7 0 012 0 0 0 0 0 8
A 22 22E7 14  8  187   3E4  5  139E4 5  6  2 1 0 1 0 1 0 0 0 0 0 1
A 22 22E7  5 24  587  86E4  7    9E7 3 85 36 6 6 3 410 6 0 0 0 014
A 22 22E7  5  6  687 143E3  1   38E5 3  7  1 3 0 0 0 0 1 0 0 1 0 1
A 22 22E7  5 13  288   5E5  1  147E5 3 20  2 5 1 0 2 0 0 0 3 0 2 1
A 22 22E7  3 22 1087 122E3  2  436E3 1  8  0 3 0 1 0 3 0 0 0 0 0 1
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A 22 22E7  5 15 1088  28E4  2  329E4 3 11  1 0 1 1 1 1 0 0 0 1 0 5
A 22 22E7  5 14 1188  28E4  1 1482E4 3 15  3 2 2 1 1 1 1 1 1 1 0 1
A 22 22E7  5  8 1188  21E3  3  246E4 6  6  1 0 0 0 0 3 0 0 0 0 1 1
A 22 22E7  5  9  489  12E4  5   78E5 3 13  2 1 4 3 0 1 0 0 0 0 0 2
A 22 22E7  5  6  887  27E3  2  185E4 2  3  1 0 0 1 0 0 0 0 0 0 0 1
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A 22 22E7  5  7  887  64E3  3  333E4 1  7  1 1 1 2 0 1 0 0 0 0 0 1
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A 22 22E7  7  6  688  85E3  1   28E5 5  5  0 1 1 1 0 0 0 0 0 0 0 2
A 22 22E7  5 12  489   8E4  3  813E4 1  3  0 2 0 0 0 1 0 0 0 0 0 0
A 22 22E7 10 14  789  23E4  2  164E5 5  7  1 1 0 3 0 1 0 1 0 0 0 0
A 22 22E7  5 16  290 602E3  7  635E5 1 58 21 7 818 0 0 0 0 0 0 0 4
A 22 22E7  5  8  886  65E3  3   47E5 1  3  0 0 0 0 0 1 0 0 0 0 0 2
B 22  2E7  8 24 1288   8E4  3   77E5 3  6  0 0 1 3 1 1 0 0 0 0 0 0
C 30 12E7  3 10 1188  18E4  9   35E5 3  9  1 0 0 0 0 5 1 2 0 0 0 1
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```

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D	30	5E7	4	18	487	3E4	3	1526E3	7	2	0	0	0	0	0	0	0	0	0	0	0	2
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F	20	35E7	3	15	686	4E5	16	42E6	3	45	013		012		8	0	5	0	0	7	0	0
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F	20	35E7	5	18	686	7E5	18	72E6	3	68	921		016		8	0	0	0	0	6	0	8
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G	8	14E6	3	10	1187	12E3	2	1291E3	1	4	1	0	0	0	0	0	2	0	0	0	0	1
G	8	14E6	15	10	388	12E3	2	1074E3	1	2	0	0	0	1	0	1	0	0	0	0	0	0
G	8	14E6	14	13	188	21E3	1	1748E3	5	2	0	0	0	0	0	0	0	0	0	1	0	1
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APPENDIX J

RESULTS OF SAS COLLINEARITY ANALYSIS

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	3	29606.26252	9868.75417	131.385	0.0001
Error	81	6084.16101	75.11310		
C Total	84	35690.42353			

Root MSE	8.66678	R-square	0.8295
Dep Mean	12.68235	Adj R-sq	0.8232
C.V.	68.33733		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	2.852724	1.61180144	1.770	0.0805
CONSIZ	1	-1.635504E-8	0.00000001	-1.868	0.0654
PROSF	1	0.000014270	0.00000811	1.760	0.0822
PRAMT	1	0.000000836	0.00000009	9.692	0.0001

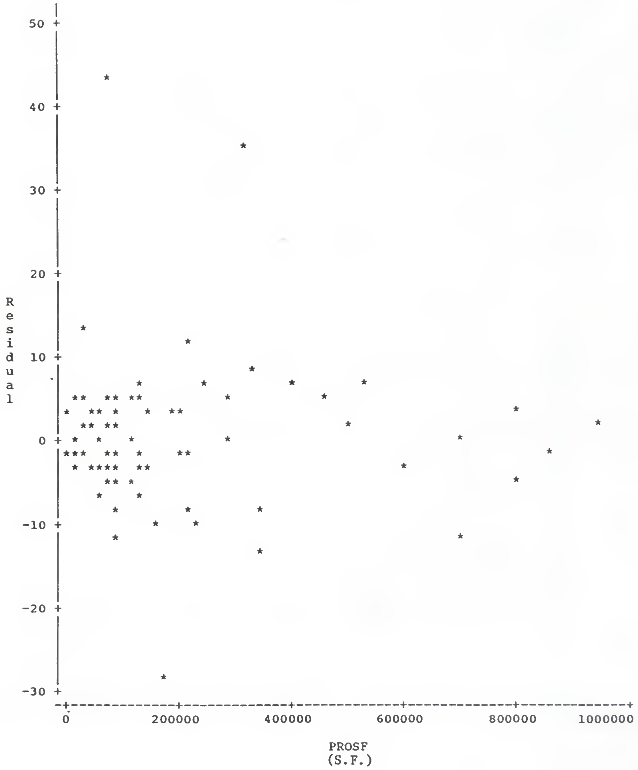
Variable	DF	Tolerance	Variance Inflation
INTERCEP	1	.	0.00000000
CONSIZ	1	0.87898517	1.13767562
PROSF	1	0.29828766	3.35246853
PRAMT	1	0.30098484	3.32242645

Collinearity Diagnostics(intercept adjusted)

Number	Eigenvalue	Condition Number	Var Prop CONSIZ	Var Prop PROSF	Var Prop PRAMT
1	2.04623	1.00000	0.0722	0.0609	0.0609
2	0.78864	1.61078	0.9270	0.0299	0.0341
3	0.16513	3.52018	0.0008	0.9092	0.9050

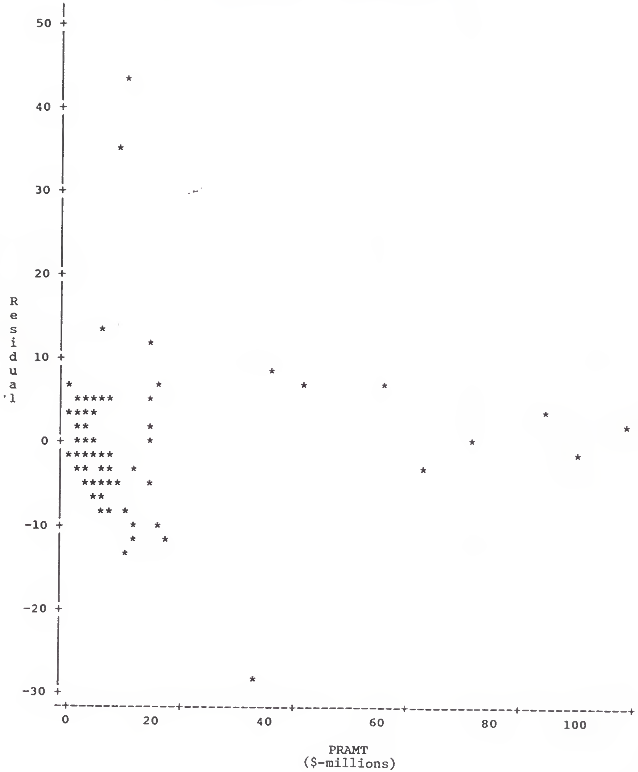
PREDICTION MODEL FOR ESTIMATED TOTAL NUMBER OF ACCIDENTS

Plot of YRESID*PROSF. Symbol used is '*'.



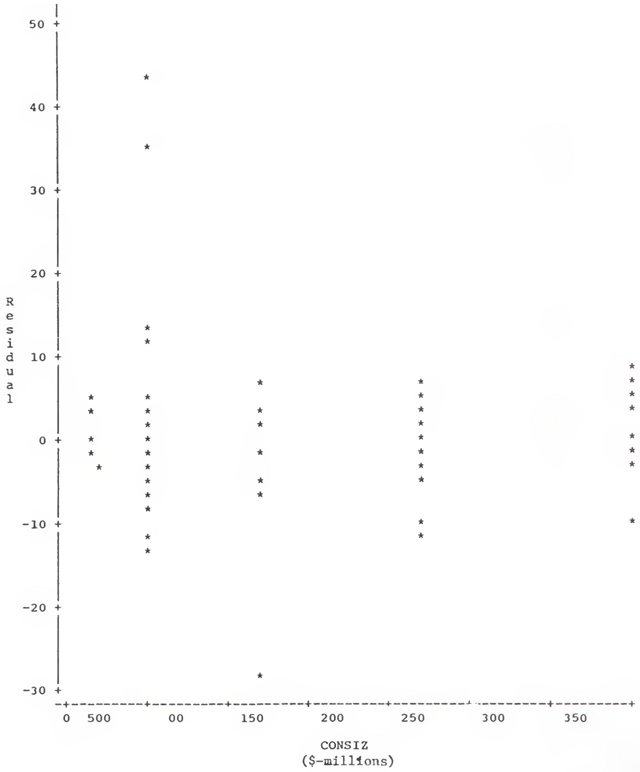
PREDICTION MODEL FOR ESTIMATED TOTAL NUMBER OF ACCIDENTS

Plot of YRESID*PRAMT. Symbol used is '*'.



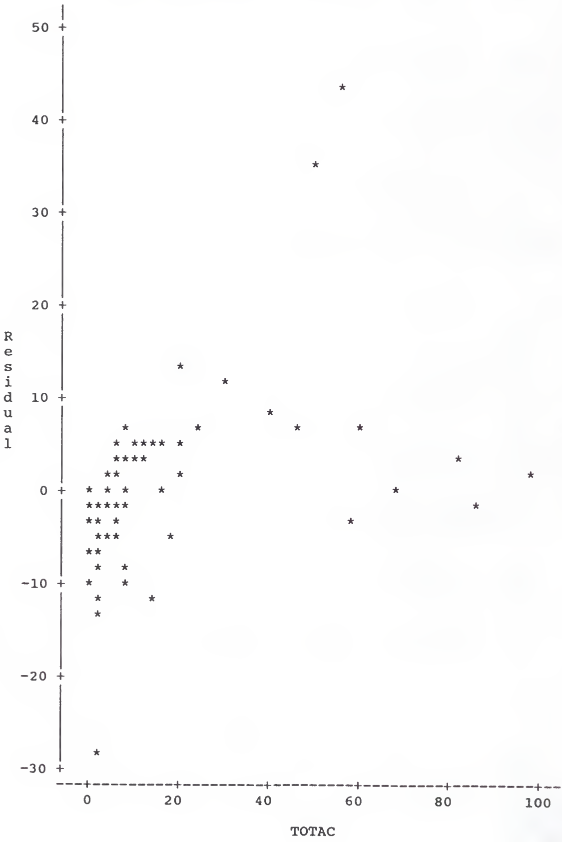
PREDICTION MODEL FOR ESTIMATED TOTAL NUMBER OF ACCIDENTS

Plot of YRESID*CONSIZ. Symbol used is '*'.



PREDICTION MODEL FOR ESTIMATED TOTAL NUMBER OF ACCIDENTS

Plot of YRESID*TOTAC. Symbol used is '*'.



PREDICTION MODEL FOR ESTIMATED TOTAL NUMBER OF ACCIDENTS

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	3	29606.26252	9868.75417	131.385	0.0001
Error	81	6084.16101	75.11310		
C Total	84	35690.42353			

Root MSE	8.66678	R-square	0.8295
Dep Mean	12.68235	Adj R-sq	0.8232
C.V.	68.33733		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	2.852724	1.61180144	1.770	0.0805
CONSIZ	1	-1.635504E-8	0.00000001	-1.868	0.0654
PROSF	1	0.000014270	0.00000811	1.760	0.0822
PRAMT	1	0.000000836	0.00000009	9.692	0.0001

APPENDIX K

EXAMPLE OF MLE TECHNIQUE

MAXIMUM LIKELIHOOD ESTIMATION (MLE) METHOD

According to Harnett (1972), The method of maximum likelihood was developed in the 1920s by R.A. Fisher. This method is used to estimate the value of a population parameter by selecting the sample space (population parameter) that would yield the observed sample more frequently than any other space. The population parameter which corresponds to this space is known as the maximum likelihood estimate of θ, and the name maximum likelihood came from the process of selecting the most likely sample space.

To illustrate the method of maximum likelihood, consider a very simple estimation problem. Suppose a commercial construction contractor had a certain number of fatal and non-fatal on a project, and suppose it is known that the ratio of the numbers of the two types of accidents is 3/1 but that it is not known whether the fatal or non-fatal accidents were more numerous. In other words, the probability of the contractor having a fatal accidents is either 1/4 or 3/4. If n accidents are taken from the total number of accidents, the distribution of X, the number of fatal accidents is, is given by the binomial distribution

$$f(x;p) = \binom{n}{x} p^x q^{n-x} \qquad \text{for } x = 0, 1, 2, \ldots, n,$$

where $q = 1-p$ and p is the probability of having a fatal accident. Here $p = 1/4$ or $p = 3/4$.

For instance, consider a sample of three accidents, that is, $n = 3$, and attempt to estimate the unknown parameter p of the distribution. In this case the estimation problem is simple because one has to choose between only two numbers, .25 and .75, and the results can be anticipated from the following possible outcomes and their probabilities

Outcome:x	0	1	2	3
f(x;3/4)	1/64	9/64	27/64	27/64
f(x;1/4)	27/64	27/64	9/64	1/64

In this example, if $x = 0$ in a sample of three accidents, the estimate .25 for p would be preferred over .75 due to the fact that the probability 27/64 is greater than 1/64, because a sample with $x = 0$ is more likely (in the sense of having larger probability) to arise from a population with $p = 1/4$ than from one with $p = 3/4$. And in general p should be estimated by .25 when $x = 0$ or 1 and by .75 when $x = 2$ or 3. The estimator may be defined as

$$\hat{p} = \hat{p}(x) = \begin{cases} .25 & \text{for } x = 0,\ 1 \\ .75 & \text{for } x = 2,\ 3. \end{cases}$$

The estimator thus selects for every possible x the value of p, say p, such that

$$f(x;\hat{p}) > f(x;p'),$$

where p' is the alternative value of p.

More generally, if several alternative values of p were possible, it may be reasonable to proceed in the same manner. Thus if it was found that x = 6 in a sample of 25 accidents from a binomial population, then all possible values of p should be substituted in the expression

$$f(6;p) = \binom{25}{6} p^6(1 - p)^{19} \qquad \text{for } 0 \le p \le 1$$

and the estimate chosen as that value of p which maximized f(6;p). For the given possible values of p, the estimate should be 6/25. The position of its maximum value can be found by putting the derivative of the function defined in the above equation with respect to p = 0 and solving the resulting equation for p. Thus

$$\frac{d}{dp} f(6;p) = \binom{25}{6} p^5(1 - p)^{18}[6(1 - p) - 19p],$$

and upon putting this equal to zero and solving for p, it can

be seen that $p = 0, 1, 6/25$ are the roots. The first two roots give a minimum, and so the estimate is therefore $\hat{p} = 6/25$. This estimate has the property that

$$f(6;\hat{p}) > f(6;p'),$$

where p' is any other value of p in the interval $0 \leq p \leq 1$.

APPENDIX L

RESULTS OF ILLUSTRATIVE MODEL VERIFICATION

PREDICTION MODEL FOR ESTIMATED TOTAL NUMBER OF ACCIDENTS

Obs	Dep Var TOTAC	Predict Value	Residual
1	.	.	.
2	60.0000	53.3096	6.6904
3	6.0000	0.8453	5.1547
4	85.0000	86.8042	-1.8042
5	7.0000	4.4736	2.5264
6	20.0000	18.6848	1.3152
7	8.0000	1.3602	6.6398
8	9.0000	5.0862	3.9138
9	11.0000	6.0019	4.9981
10	15.0000	15.6458	-0.6458
11	6.0000	1.6119	4.3881
12	13.0000	7.4910	5.5090
13	3.0000	1.1873	1.8127
14	5.0000	1.6759	3.3241
15	7.0000	2.9531	4.0469
16	4.0000	5.4296	-1.4296
17	13.0000	24.1065	-11.1065
18	18.0000	22.6980	-4.6980
19	5.0000	1.8461	3.1539
20	7.0000	8.6134	-1.6134
21	4.0000	2.5965	1.4035
22	5.0000	2.8095	2.1905
23	3.0000	7.1963	-4.1963
24	7.0000	16.2539	-9.2539
25	58.0000	60.9575	-2.9575
26	3.0000	4.1133	-1.1133
27	6.0000	10.1076	-4.1076
28	9.0000	6.3861	2.6139
29	2.0000	30.6526	-28.6526
30	1.0000	6.9986	-5.9986
31	23.0000	16.8611	6.1389
32	2.0000	7.2544	-5.2544
33	4.0000	6.0425	-2.0425
34	98.0	96.9	1.1011
35	1.0000	9.0198	-8.0198
36	1.0000	9.3601	-8.3601
37	1.0000	12.6035	-11.6035
38	2.0000	3.6079	-1.6079
39	4.0000	9.7801	-5.7801
40	7.0000	14.8729	-7.8729
41	4.0000	5.4881	-1.4881
42	49.0000	13.8451	35.1549
43	19.0000	13.4589	5.5411
44	1.0000	3.5712	-2.5712
45	8.0000	7.5877	0.4123
46	2.0000	3.7394	-1.7394
47	11.0000	6.5259	4.4741
48	1.0000	3.2519	-2.2519

PREDICTION MODEL FOR ESTIMATED TOTAL NUMBER OF ACCIDENTS

Obs	Dep Var TOTAC	Predict Value	Residual
49	6.0000	3.2371	2.7629
50	5.0000	3.7761	1.2239
51	29.0000	17.2453	11.7547
52	2.0000	6.3563	-4.3563
53	55.0000	11.4678	43.5322
54	1.0000	3.1568	-2.1568
55	20.0000	6.7146	13.2854
56	1.0000	5.6666	-4.6666
57	3.0000	8.5653	-5.5653
58	1.0000	14.9308	-13.9308
59	1.0000	3.9550	-2.9550
60	0	6.5017	-6.5017
61	2.0000	5.5040	-3.5040
62	11.0000	6.8495	4.1505
63	5.0000	9.5159	-4.5159
64	4.0000	4.7902	-0.7902
65	2.0000	3.6611	-1.6611
66	6.0000	7.2310	-1.2310
67	0	1.5321	-1.5321
68	0	0.4300	-0.4300
69	0	1.8396	-1.8396
70	0	3.9307	-3.9307
71	45.0000	37.9659	7.0341
72	16.0000	10.7505	5.2495
73	0	9.3059	-9.3059
74	68.0000	67.3394	0.6606
75	82.0000	78.8462	3.1538
76	2.0000	4.9811	-2.9811
77	39.0000	31.1692	7.8308
78	0	3.9307	-3.9307
79	5.0000	8.0217	-3.0217
80	2.0000	2.8631	-0.8631
81	4.0000	3.8748	0.1252
82	2.0000	3.6933	-1.6933
83	2.0000	4.3855	-2.3855
84	3.0000	4.4648	-1.4648
85	10.0000	4.3927	5.6073
86	6.0000	3.4922	2.5078

Sum of Residuals 4.751755E-14
Sum of Squared Residuals 6084.1610
Predicted Resid SS (Press)6673.1293

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BIOGRAPHICAL SKETCH

Kweku Bentil obtained his Bachelor of Science degree in building science and construction management in 1974 from Pratt Institute in Brooklyn, New York.

He entered the graduate program in building construction at the University of Florida in the fall of 1974 and was awarded a Master of Science degree in June 1975. Between 1975 and 1978 he was employed by the joint venture of Parsons Brinckerhoff Quade & Douglas, Tudor Engineering and Bechtel Corporation (the consulting engineers on the design and construction of Atlanta's Rapid Transit System) initially as an estimator. After implementing a computerized estimating system and training estimating personnel, he was appointed a Senior Field Engineer on three simultaneous projects.

From 1978 to 1980 he was employed as the Regional Director and Construction Manager (Southeastern Operations) for MCAP Inc., where he was responsible for their operations in eight states in the Southeast. From 1980 to 1985 he was employed as the General and Construction Manager for a general contractor, where he managed a 25-man office in addition to project responsibilities in ten states.

In 1985, he resigned from industry to accept a teaching position in the School of Building Construction at the University of Florida. In 1986, he started taking classes in the Department of Civil Engineering towards a doctoral degree on a part-time basis. In 1987 he was awarded a McKnight Junior Faculty Fellowship by the Florida Endowment Fund for Higher Education to enable him to work on a full-time basis towards the degree of Doctor of Philosophy in the Department of Civil Engineering at the University of Florida.

In 1988 he was awarded an Auzenne Fellowship for one year, by the Board of Regents of the State of Florida, to enable him to complete his doctoral studies. In 1989, he returned to full-time teaching in the School of Building Construction while working towards completing the requirements for the degree of Doctor of Philosophy.

He is married to Phyllis Barbara and they have three children: Daniel (23), Sandra (12) and Leslie (10).

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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